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Energy Performance Analysis of Mandatory Design Codes and Voluntary Green Building Programs Under Different Climate Change Scenarios Using Urban Building Energy Modeling Tools. A Case in Austin, Texas

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Energy Performance Analysis of Mandatory Design Codes and Voluntary Green Building Programs Under Different Climate Change Scenarios Using Urban Building Energy Modeling Tools. A Case in Austin, Texas

by

Jose Alejandro Ng Osorio

Thesis

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Abstract

Energy Performance Analysis of Mandatory Design Codes and Voluntary Green Building Programs Under Different Climate Change Scenarios Using Urban Building Energy Modeling Tools. A Case in Austin, Texas

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The University of Texas at Austin, 2019

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According to the U.S. Energy Information Administration (U.S. EIA) (2018a), in 2017 the energy delivered to the residential and commercial building sector represented 27% of the total delivered energy in the United States. In the case of greenhouse emissions (GHG), the building sector represented around 40% emissions in the country (U.S. EIA, 2017). Anthropogenic GHG emissions are considered the main cause of climate change. One of the most notable consequences of climate change is the temperature rise. For the Austin area is expected the temperature rise between 2.6ºC to 4.5ºC by 2100 in comparison to the average temperature observed between 1990 and 2010 (Hayhoe, 2014). Also, building design and construction in the United States has been regulated by different codes and standards. In the case of building energy performance, there exist both mandatory codes and voluntary green building certifications to increase building energy performance.

Using Urban Building Energy Modeling tools (UBEM), in this case, the urban modeling interface (UMI), this thesis analyzes the building energy performance of different mandatory design codes and voluntary green building certifications under three different climate change scenarios. UBEM tools are capable to perform an urban scale energy simulation. Mueller neighborhood located in Austin, Texas was the location selected for the modeling and simulation process for this thesis. The three different emission scenarios projected by the Intergovernmental Panel on Climate Change were used for this thesis, are A2, A1B, and B1. On the other hand, building templates analyzed are the International Code Council mandatory codes used in Austin, the Leadership in Energy and Environmental Design (LEED) voluntary certification and the Austin Energy Green Building (AEGB) voluntary certification.

Results from the simulation process show that it is mostly inevitable to avoid the effects of climate change in the energy performance of the building. However, buildings designed under the different green building certification requirements presented the most resistance against the increase of temperature. This methodology helps to identify the impact of climate change in buildings and can be used as feedback for policy making, climate change mitigation, and energy strategic analysis.

Keywords: *urban building energy modeling; climate change emission scenario; voluntary green building certification; mandatory building energy conservation code; urban modeling interface*

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Chapter 1: Introduction

1.1. Background

According to the U.S. Energy Information Administration (U.S. EIA) (2018a), in 2017 the energy delivered to the residential and commercial building sector represented 27% of the total delivered energy in the United States. In the case of the greenhouse emissions (GHG), the building sector represented around 40% emissions in the country (U.S. EIA, 2017). Urban areas account for 70% of the GHG emissions in the world (Deetjen, Conger, Leibowicz, & Webber, 2018).

Anthropogenic GHG emissions are considered the main cause of climate change. One of the most notable consequences of climate change is the temperature rise. The Intergovernmental Panel on Climate Change (IPCC) has developed several GHG emissions scenarios to forecast the temperature rise in the future. Scenarios vary from low to high GHG emissions and are attached to political, social, and economic changes in the world. For the Austin area is expected the temperature rise between 2.6ºC to 4.5ºC by 2100 in comparison to the average temperature observed between 1990 and 2010 (Hayhoe, 2014).

Following international treaties, including the 2014 Paris agreement, several cities are developing plans to reduce GHG emissions. For example, San Francisco wishes to reduce 40% of its GHG emissions, London 60%, and New York City 80% (Reinhart & Cerezo, 2016). In the case of Austin, TX, the City Council has set the goal to reach net-zero GHG emissions by 2050 (City of Austin, 2015).

Since several decades ago, the building design and construction in the United States has been regulated by different codes and standards. In the case of building energy performance, there exist both mandatory and voluntary regulations to increase energy efficiency. For example, in Texas is mandatory to design commercial buildings following the 2015 International Energy Conservation Code requirements. On the other hand, a project can be designed and constructed following a voluntary rating system such as the Leadership in Energy and Environmental Design (LEED) certification.

Improvements in appliance efficiency and the development of stringent building energy codes are changing the consumption growth rates. It is expected a modest growth rate of 0.3% per year of energy delivered from 2017 to 2050 accounting for the 26% of the total energy delivered in the country (U.S. EIA, 2018a). However, rapid population growth in U.S. Metropolitan Statistical Areas (MSA) such as the Austin-Round Rock MSA and the consequent urban growth patterns are pushing the energy systems of the region.

For 2050, it is expected that the Austin-Round Rock MSA population will be around 4.5 million people, representing a 165%-growth in 30 years (Texas Demographic Center, 2018). The recent population growth in the Austin area has been translated into urban sprawl and low-density urban development. Now, Austin is not only considered the fastest growing metropolitan area in the country but also one of the most sprawled.

1.2. Objective

Considering that population growth can be traduced into an increase of the demand of natural resources and residential units. The objective of this research is to estimate the building energy consumption in the Austin area using an Urban Building Energy Model (UBEM) software. At the same time, energy consumption estimation will be evaluated using different mandatory and voluntary energy performance regulations and climate change scenarios projected by the IPCC.

Through the results obtained from the simulation process, we will be able to understand future building energy performance scenarios and influence mandatory and voluntary regulations to create more sustainable and resilient projects.

1.3. Research Question

Main Question:

- How do different mandatory and voluntary building energy codes and certifications perform under different climate change scenarios in the Austin, TX area?

Secondary Question:

- How significant is the change in energy consumption simulated for 2050 and 2100 in comparison to current consumption?

1.4. Methodology

The methodology used in this thesis includes the steps are presented below. Also, Figure 1.1 presents the research methodology workflow and Table 1.1 the results matrix.

- Background review of population growth in the State of Texas and the Austin-Round Rock MSA.
- A review of the different climate change scenarios estimated for the Austin area and obtain weather files for both actual and climate change scenarios using the Meteonorm software.
- Explore the different mandatory and voluntary energy performance codes and standards applicable in the Austin area. Data gathering of the different codes and standards requirements.
- Selection UBEM software and the neighborhood to be modeled.
- Creation of a computerized model and energy simulation using datasets from ArcGIS, energy performance requirements from energy codes and standards, and climate files for different years.

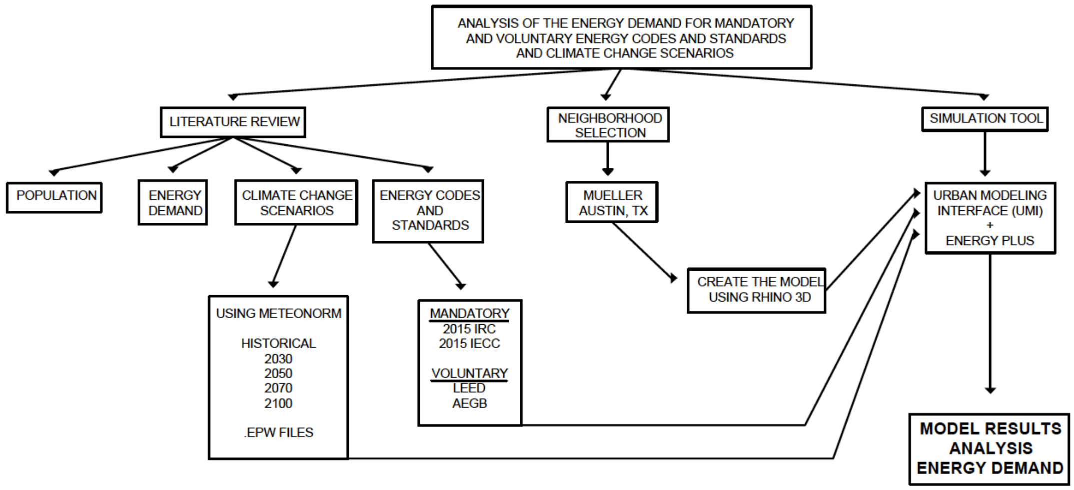


Figure 1.1: Methodology flowchart.

<table>
<tr><td colspan="2" rowspan="4"></td><td colspan="5">Climate Change Scenarios (GHG Emissions Scenarios)</td></tr>
<tr><td colspan="2">A1B</td><td>A2</td><td colspan="2">B1</td></tr>
<tr><td colspan="5">Years</td></tr>
<tr><td>Historical</td><td>2030</td><td>2050</td><td>2070</td><td>2100</td></tr>
<tr><td rowspan="3">Mandatory and Voluntary Energy Codes and Standards</td><td>ICC</td><td colspan="5" rowspan="3">ENERGY CONSUMPTION</td></tr>
<tr><td>LEED</td></tr>
<tr><td>AEGB</td></tr>
</table>

Table 1.1: Results matrix.

Chapter 2: The Urban Context in Texas and Austin

This thesis studies the impact of climate change and different construction standards to the building energy performance in the urban context. To understand how urbanization impacts energy demand, it is important to study the population growth and urban evolution and its relationship to climate change. This chapter presents a brief analysis of the population and urban growth in Texas and Austin. Also, the impact on the demand of resources.

2.1. Population Growth

2.1.1. Texas

A report from the U. S. Census Bureau (2018a) revealed that Texas, between July 2017 and July 2018, gained more residents than any other state in the country, around 379,178 new residents, representing a 1.3% population growth. In 2018, Texas population was estimated to 28,701,845 persons. The reasons of the increase of population are more births than deaths and net gains due to migration from inside and outside the United States (U.S. Census Bureau, 2018c). The numbers reported by the U.S. Census Bureau are not strange taking in count the demographic history of the state. Population in Texas has increased more rapidly in percentage terms than the national rate in every decade since Texas became a state.

For Texas, the 1990s decade was very important in terms of demography because the state surpassed New York and became the second largest state by population (Murdock et al., 2003). In that decade the population number significantly exploded. For example, from 1990 to 2000 population in Texas increased by 3,865,310 persons, representing an increasing rate of 22.8% and a total population of 20,851,820. Again, in the decade of 2000s Texas population, significative increased. From 2000 to 2010 the Texas population grew by 4,293,741 persons, representing an increasing rate of 20.59%. In this decade the state population growth accounted for one-fifth of the 1910-2010 century population growth (White et al., 2017a).

As explained before, high population growth rates are expected in Texas for the next decades due to natural growth and migration high rates. According to the Texas Demographic Center (You, Potter, Valencia, & Robinson, 2019), it is expected that population increase to 47.3 million persons by 2050 taking in count migration rates observed from 2010 to 2015. It represents an 88.5% of population increase in comparison to 2010. On the other hand, if migration rates observed from 2000 to 2010 are taking into the count, state population is expected to be 54.4 million persons by 2050. Figure 2.1 presents Texas' census population from 1990 to 2010 and the projected population from 2020 to 2050.

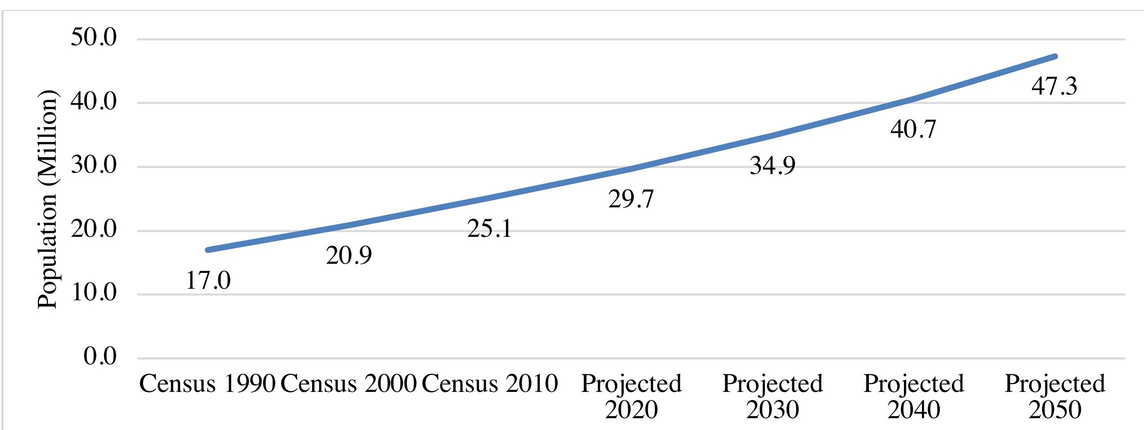


Figure 2.1: Population growth in Texas from 1990 to 2050. Source: Texas Demographic Center. *"Texas Population Projections 2010 to 2050"* (2019) (You et al., 2019)

According to the U.S. Census Bureau (2018a), two Texan Metropolitan Statistical Areas (MSA) are included in the U.S. top-ten MSAs by population. The Dallas-Fort Worth-

Arlington, TX MSA is in the 3rd position with 7,399,622 persons and the Houston-The Woodlands-Sugar Land, TX MSA in the 4th position with 6,892,427 persons. Also, other important Texas' MSAs are the San Antonio-New Braunfels, TX MSA located in the position 24th by population with 2,473,974 persons and the Austin-Round Rock, TX MSA in the position 31st with 2,115,827 persons.

For 2050, steady population growth rates for the main Texan MSAs are expected. The Texas Demographic Center (2018) projects for 2050 a population of 13,173,646 persons for the Dallas-Fort Worth-Arlington, TX MSA, representing an increase of 106.9% in comparison to the 2010 census; 13,155,993 persons for the Houston-The Woodlands-Sugar Land, TX MSA, representing an increase of 122.2%; 4,459,030 persons for the San Antonio-New Braunfels, TX MSA, representing an increase of 108.1%; and 4,542,857 persons for the Austin-Round-Rock, TX MSA, representing an increase of 164.6%. Figure 2.2 presents the population evolution in the four main Texan MSAs.

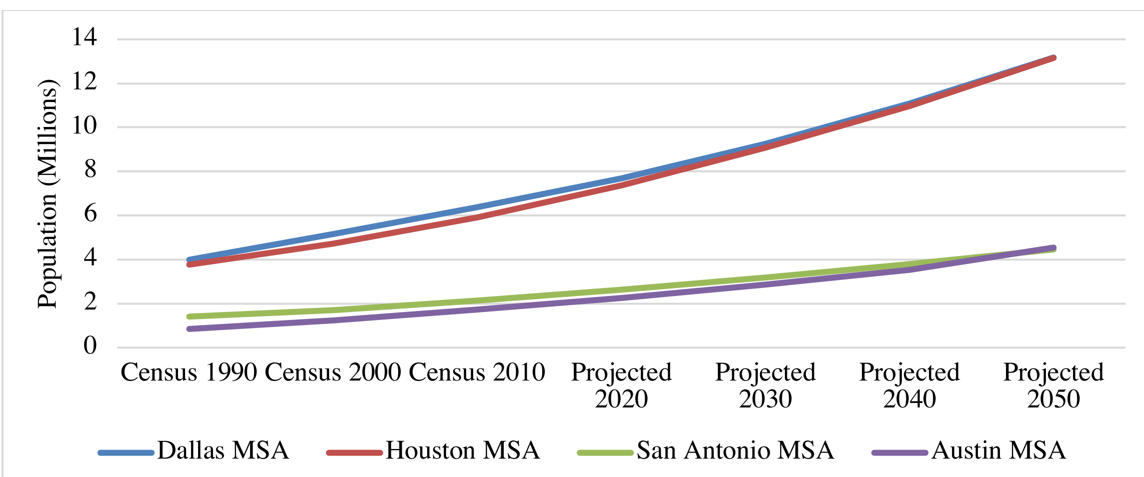


Figure 2.2: Texan MSAs urban evolution. Source: Texas Demographic Center. *"2018 Texas Population Projections Data Tool Result"* (2018) and U.S. Census Bureau, *"U.S. Census 2000"* (2003)

Texas is widely known for its vast amount of area and is often considered as non-metropolitan or rural. However, the actual urban-rural share of population in the state reveals a more metropolitan character. The urban population growth in Texas has been the growing trend in the last 100 years, like the rest of the United States and the world. In 2010. Around 85% of the population lived in urban areas, while 15% in rural areas (White et al., 2017b). Figure 2.3 presents the urban-rural share population in Texas from 1910 to 2010.

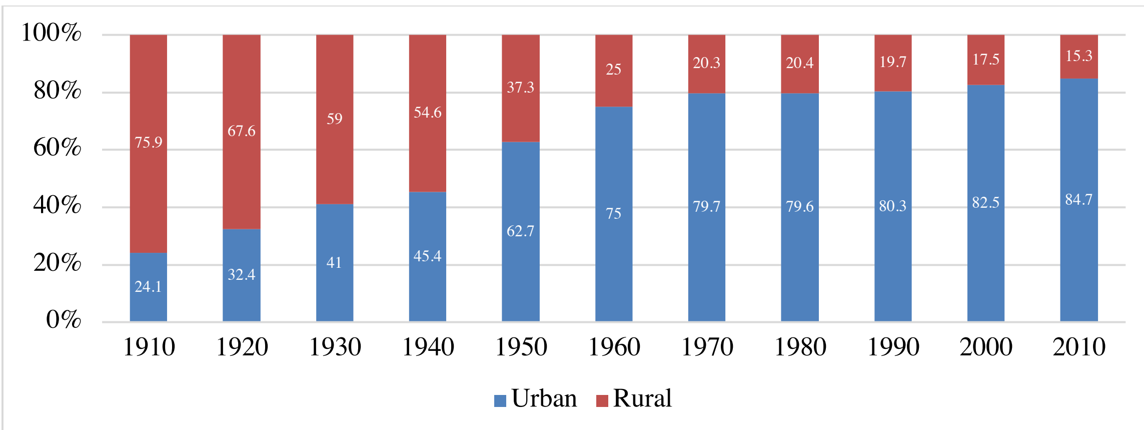


Figure 2.3: Urban-Rural population share evolution in Texas from 1910 to 2010. Source: Texas Demographic Center. *"Urban Texas"* (2017). (White et al., 2017)

According to a Texas Demographic Center (White et al., 2017b) report, the population growth rate in rural counties is 0.3%. On the other hand, urban counties population is growing at a 1.7% rate. Taking in count the estimated rates, in 2050, rural counties only will account the 5.4% of population growth in the state, while urban counties the 94.5%. That means Texas' population future scenario will occur in cities.

The rapid increase of population can result in a high demand for resources and services, especially in a high urban growth scenario. For example, the population will require potable water, electricity, waste management, emergency management systems, public transit, transportation infrastructure, housing, education facilities, land, among other services. A brief analysis is presented later in this chapter.

2.1.2. Austin

The urban area studied in this thesis is the capital area of the state of Texas, Austin. Currently, Austin is the fourth most populated MSA in the state and the thirty-first most populated in the country. The case of Austin is special because it is expected that Austin will surpass San Antonio by 2050 and become the third largest MSA in the state.

The Office of Management and Budget designed the Greater Austin Area as the Austin-Round Rock MSA. The metropolitan area consists of five counties, Bastrop, Caldwell, Hays, Travis, and Williamson (Office of Management and Budget, 2013). Principal cities of the MSA are Austin and Round Rock. Also, the MSA includes other important mid-size and small cities such as Cedar Park, San Marcos, Georgetown, Pflugerville, Buda, Kyle, Leander, among others. Figure 2.4 presents the county political division map of the MSA.

In 2018, the Austin-Round Rock MSA population was 2,115,827 persons. The main city of the MSA, Austin, has a population of 950,715 persons (U.S. Census Bureau, 2018b). Population in the MSA is distributed in the among the different counties as follows Travis County 1,176,584 persons, Williamson County 508,313 persons, Hays County 194,843 persons, Bastrop County 80,306 persons, and Caldwell County 40,544 persons (U.S. Census Bureau, 2018e).

The Austin-Round Rock MSA is considered the fastest growing MSA in the state and the ninth in the country (Ura & Daniel, 2018). The main reasons for the high population increase are both domestic and international migration. From 2010 to 2014 the domestic migration accounted for the 50% of the population growth, international migration for

20%, and the natural increase for 30%. Considering the counties, migration represented the 60% growth for the Travis County and the 77% for the surrounding counties.

According to an Austin Area Sustainability Indicators report (RGK Center for Philanthropy and Community Service, LBJ School of Public Affairs & The University of Texas at Austin, 2016), the Travis and Williamson counties have increased by around 200,000 persons every decade since 1990. Between 2010 and 2014, Hays County leaded population growth in the MSA with a 14.4% population growth. Hays County was followed by Williamson County with an 11% population growth rate, the Travis County with 10%, the Bastrop County with 7%, and the Caldwell County with 3%. In 2016, the Hays County was considered the fastest-growing county in the country (U.S. Census Bureau, 2018d). According to Figure 2.5 suburbs gained more pouplation while several central areas lost population.

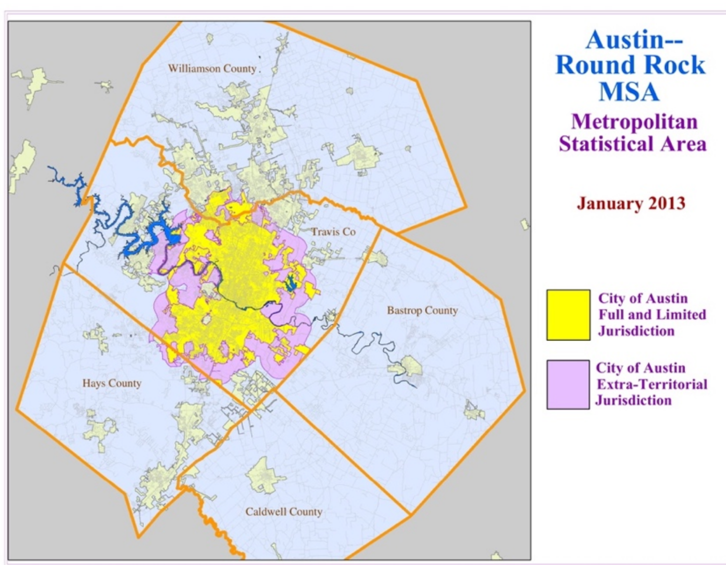


Figure 2.4: County division of the Austin-Round Rock MSA and the Austin city limits. (City of Austin, 2013)

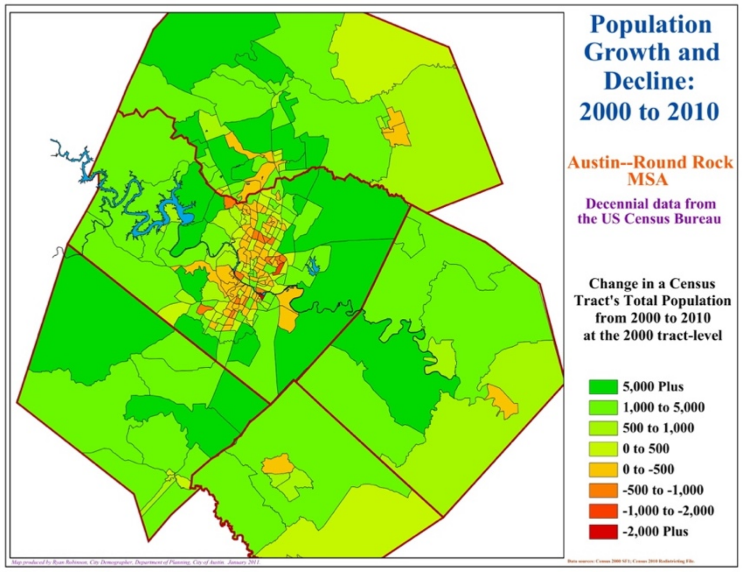


Figure 2.5: A comparison of population growth and decline by track level between 2000 and 2010 census. (City of Austin, 2011)

According to U.S. News & World Report (2018), Austin is considered the best place to live in the United States and the fourth to retire. The city is an attractive destination for people because of its quality of life, low prices, low state and local taxes, no personal or corporate income tax, the cultural scene, and attractive jobs. Also, big firms and companies are locating their headquarters or second headquarters in Austin. Therefore, it is expected city population will increase due to workforce demand and the other reasons mentioned above.

2.2. Urban Growth

The term urban growth is most of the times directly related to the population growth in an urban area. Initially, it was associated with the movement of people from a rural area to an urban area. However, now the term is also applicable to the movement of people between two urban areas. Also, the term urban growth can be used as a synonym of urban sprawl. Depending on the case, urban growth can be associated with the increase or decrease of density in a specific urban area.

Cities growth patterns have been changing dramatically in the last century, especially in the United States. Urban sprawl in America started in the mid-1920s with an acceleration after 1950. The sprawl is a result of different factors such as lower land rates, lower house tax rates, cultural preferences, lack of urban planning, and especially the rise in population growth. Also, it is directly related to the postwar era of mass car ownership and its consequent increase in energy demand. Over the years, cities have suffered the consequences of urban sprawl - for example, greater air pollution, reduced open space, increased runoff of stormwater, ecosystem fragmentation, loss of farmland, and higher energy consumption.

Suburban sprawl is considered the standard North American pattern of growth. Tsai (2004) defines the term “sprawl” by land use and structural characteristics such as, low number of people inhabiting a given urbanized area; scattered development, where commercial and residential are not close together; leapfrog development, where large amounts of vacant land abounds; and strip commercial development, where retail is concentrated only on main avenues. Schmidt (2004) states other characteristics such as a poor mix of homes, jobs, and services; reduced number of recreational centers in downtown areas; and limited reliable options of alternative transportation methods (e.g. walking, biking, and public transportation).

The impacts of such growth patterns include the increase of the Urban Heat Island Effect, deforestation and loss of habitat, air pollution due to vehicle dependence, obesity, and water quality reduction (Frumkin, 2002). On the other hand, compact development can help to reduce energy consumption, fuel dependency, and increase connectivity. This is supported with the use of stringent building codes, energy efficiency policies, and lastly, sustainable design and construction voluntary standards.

Population growth in Texas resulted in an increase in the demand for places to live. Between 2006 to 2011, construction of residential units declined due to the 2008 financial crisis. However, the Texan housing market increased in the decade of 2010s. For example, between 2010 and 2017 the number of housing units increased in 892,916 units representing a 9.18% growth rate (U.S. Census Bureau, 2018d). Of the 10,611,386 housing units existing in 2017, 88.9% were occupied. Also, it is important to mention that Texas is dominated by 1-unit detached housing structures, the 65.3% were considered as such type. It is expected that Texas will require to add 10.5 million housing units by 2050 to satisfy the housing demand (Hopkins, 2013).

Generally, construction of new residential areas translates to increase of developed land area by conversion of farmland. In the case of the Austin-Round Rock MSA, urban development is considered low-dense and not-compact. According to a City of Austin (2016) report, Austin's city land sprawled from 53 square miles in 1970 to around 300 square miles in 2010. Figure 2.6 presents an urban land development between 1995 and 2015 in Austin.

Despite the increase of multi-family building permits, the MSA housing offer is mainly based on single-family homes (RGK Center for Philanthropy and Community Service, LBJ School of Public Affairs, The University of Texas at Austin, 2016). If Austin continues the sprawl development pattern, the community will face problems such as the increase of traffic congestion, pollution, and financially unsustainable infrastructure (City of Austin, 2016).

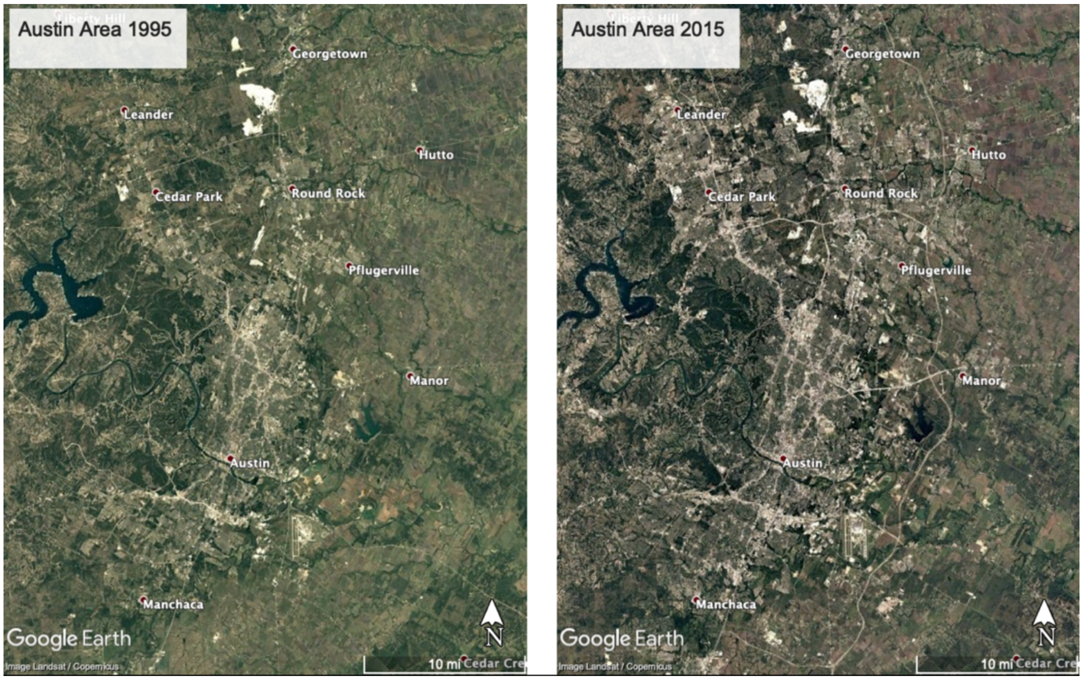


Figure 2.6. Urban Sprawl in the Austin Area, comparison between 1995 (left) and 2015 (right). Source: Google Earth Pro v7.3.2.

2.3. Energy Resources Demand

Population growth stresses existing ecosystems resulting in the demand increase for natural resources, services, and infrastructure. For example, water, energy, green spaces, housing, cultural facilities, commercial facilities, telecommunications, roads, education, human services, emergency management, among others. For the case of this thesis, only the energy demand is studied.

In energy terms, Texas is a giant not only in the United States but also in the world. According to a report from the U.S. Energy Information Administration (U.S. EIA, 2018d), in 2016 the 20.3% of the energy produced in the country was produced in Texas, around 17,080 trillion BTU. Texas leads in crude oil production (40.7% share in 2017), in marketed natural gas production (24.4% share in 2017), and in petroleum refinery capacity (30.5% in 2017). On the other hand, the state is abundant in renewable energy resources.

Texas has the largest wind-powered capacity in the country (21,450 MW in 2016) and the largest solar power potential in the country.

Regarding energy consumption, Texas is the state that consumes the most energy in the country, 13,183 trillion BTU in 2016 and in comparison, to the second largest consumer, California, 40.6% more energy. The heavy industrial activity is the main reason for the large energy consumption rates, representing 50.4% of the energy consumption in the state and 21.1% in the country (U.S. EIA, 2018d). However, Texas ranks sixth in energy consumption per capita, a list led by Louisiana (U.S. EIA, 2018c). Figure 2.7 presents the energy use share per sector in Texas. In 2017, Texas was the state that generated the most electricity in the country, 452,794 GWh (U.S. EIA, 2019b).

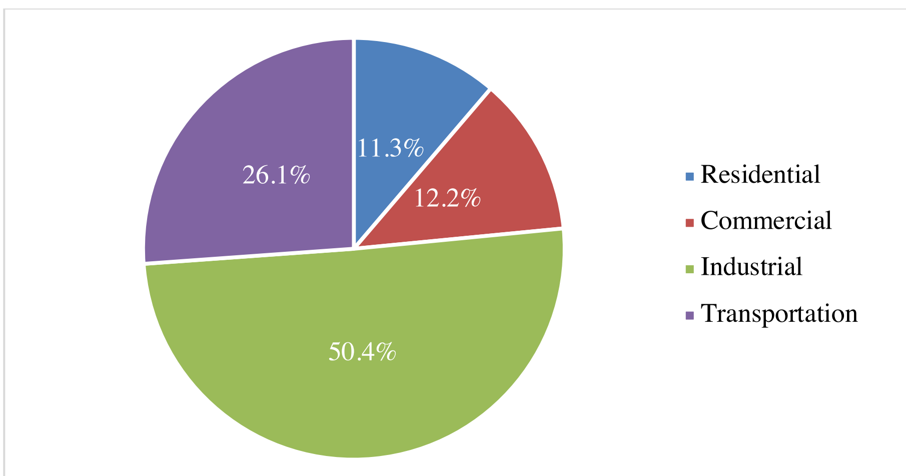


Figure 2.7: Energy use in Texas breakdown by end-use sector, 2016. Source: U.S. Energy Information Administration. *"Texas State Energy Profile"* (2018d).

The Electric Reliability Council of Texas (ERCOT) is in charge to manage the electric power on the Texas Interconnection that supplies around 90% of the electric load. ERCOT divides the peak demand into summer and winter season. The actual peak hourly load demand record, 73,259 MW, was registered on July 19, 2018, at 5:00 p.m. (U.S. EIA, 2018b). Before that event the record was set on August 11, 2016, at 5:00 p.m. Texas' electricity demand is sensitive to the weather conditions. Figure 2.8 presents the difference between the 2016's summer and winter peak hourly load. In that case, the demand increase associated with weather conditions was around 53% of the peak and it was mainly based on residential demand (Rhodes, 2018). Not only population growth but also climate change effects are stressing the Texan electric market.

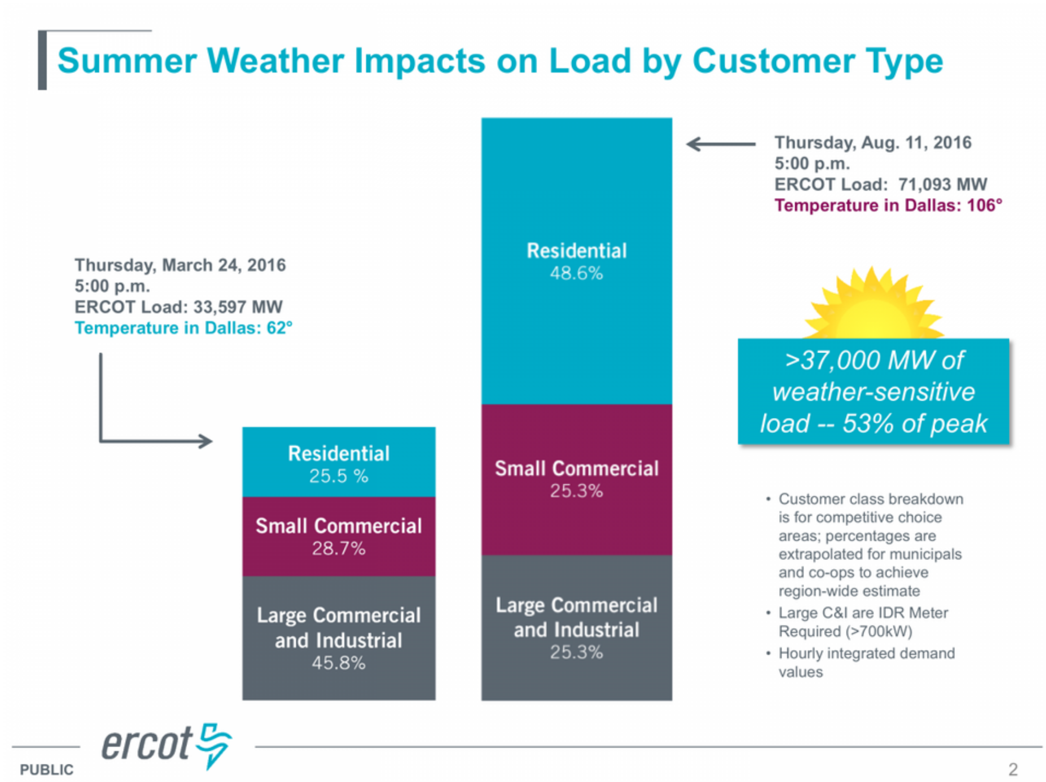


Figure 2.8: Comparison between summer and winter peak hourly load events in 2016. (Rhodes, 2018)

As explained in Figure 2.8, the residential sector highly influences electricity demand. According to the U.S EIA's 2009 Residential Energy Consumption Survey (RECS), in Texas' households the average energy consumption was 77 million Btu per year excluding transportation, 14% less in comparison to the national average. In the case of electricity only, in Texas the average consumption was 15,000 kWh per year, 26% higher in comparison to the national average. Also, the average annual electricity cost per household is considered one of the highest in the country.

Figure 2.9 presents a comparison between the average end uses in Texas and the United States. An important factor to consider is the electric cooling predominance in warm weather zones when compared to the diversity of fuels for heating in cold weather zones. In the case of Austin, average electricity residential consumption is around 1,000 kWh per month. Usage is high in summer months and low in winter months. It can be deduced that cooling equipment causes an important pressure on the electric demand because the difference between summer and winter electricity consumption is almost double. Figure 2.10 presents electricity consumption by month from 2010 to 2015.

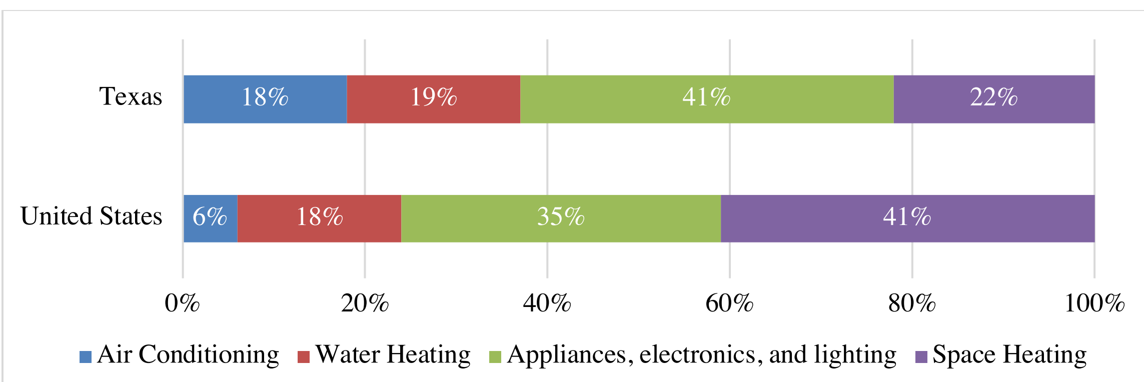


Figure 2.9: Comparison between Texas and the United States consumption by end use. Source: U.S. Energy Information Administration. *"Household Energy Use in Texas"* (2009)

Around two-thirds of the housing units in Texas are single-family units. Also, on average Texas' homes are newer and smaller in comparison with the rest of the country. United States' housing unit average square footage is 1,971 sq.ft., while Texas' average area is 1,757 sq.ft. (U.S. EIA, 2009). On the other hand, the high amount of new homes can be associated with the population growth in the state in the last decades. Figure 2.11 presents the year of construction breakdown comparison between Texas and the United States.

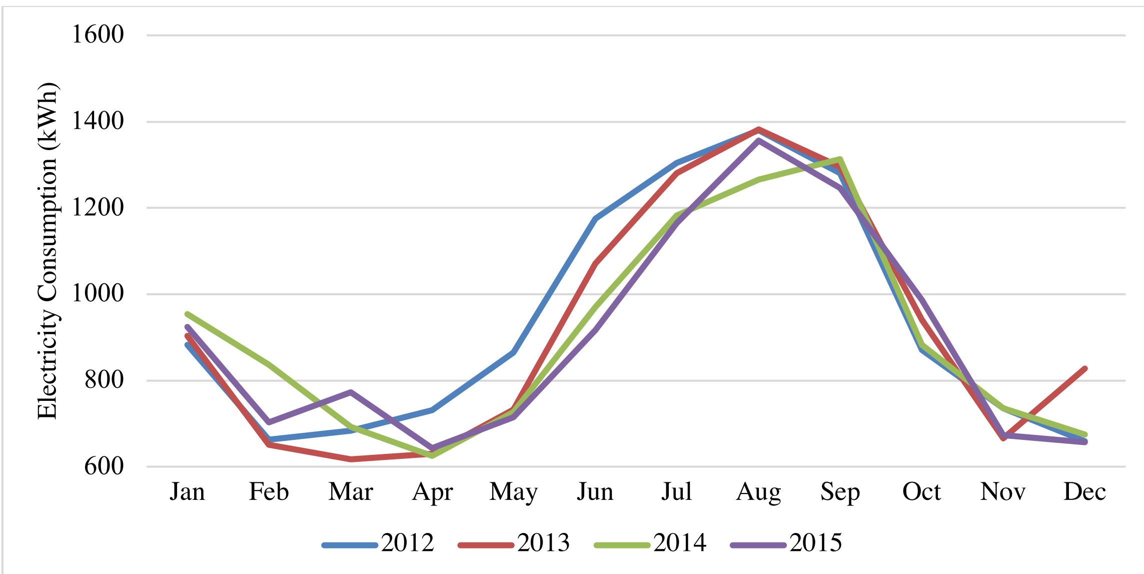


Figure 2.10: Average electricity consumption per month. Source: City of Austin. *"Residential Average Monthly kWh and Bills"* (2019)

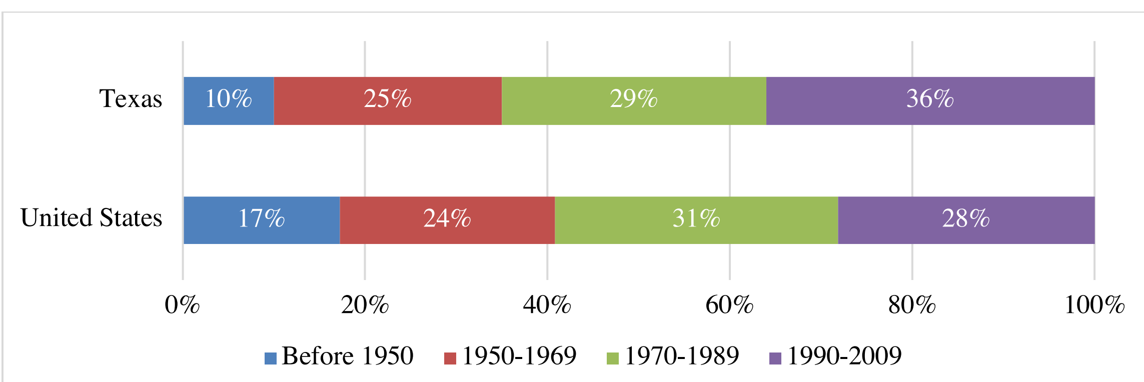


Figure 2.11: Housing units' year of construction comparison between the United States and Texas. Source: U.S. Energy Information Administration. *"Household Energy Use in Texas"* (2009)

The 2019 Annual Energy Outlook projects a 0.2% annual increase of energy consumption from 2019 to 2050 in both residential and commercial buildings. However, consumption is expected to slowly decrease, around 0.1% per year, in residential buildings due to energy efficiency improvements (U.S. EIA, 2019a). Figure 2.12 presents the energy consumption projections for both residential and commercial buildings in the United States. None of the projections presented includes the electricity demand expected from electric vehicles.

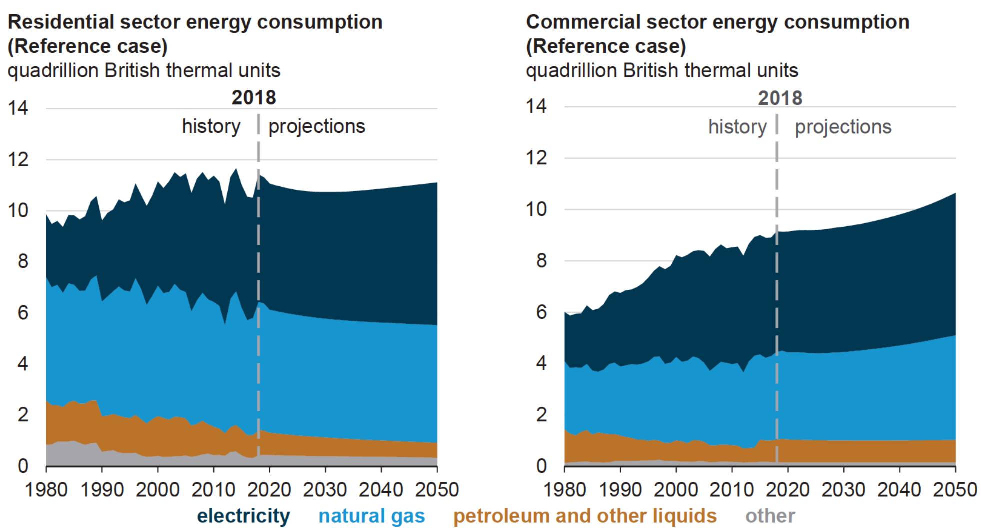


Figure 2.12: United States residential and commercial buildings energy consumption history and projections. Source: U.S. Energy Information Administration. *"2019 Annual Energy Outlook"* (2019a)

Chapter 3: Climate Change

Population and urban growth are not the only factors to take in consideration to analyze and predict future energy demand. The demand is also sensitive to climate change. In this chapter the climate change concept, causes, and consequences are briefly explained. Then, the climate change/emissions scenarios developed by The Intergovernmental Panel on Climate Change (IPCC) are examined. Also, climate change futures developed by the U.S. Global Change Research Program for the State of Texas are discussed. Finally, climate change projections for the Austin Area and scenarios used for the modeling and simulation process are presented.

It is important to mention that this thesis mainly makes reference to the effects of global warming (the increase of temperature), however other climate change effects are taking into consideration by the climate files used in the modeling and simulation process.

3.1. Concept, causes, and consequences

According to the U.S. Global Change Research Program (n.d.), climate change can be defined as the change in average weather conditions persisting in multiple decades or longer. Climate change includes both decrease or increase of temperatures, changes in precipitation levels, changes on the risk and typical cycle of severe weather events and change in physical aspects of the planet (e.g. ice mass loss).

Sometimes the term climate change is interchanged with global warming. It is important to mention that both terms are making reference to two different concepts, usually related to timeframe. Global warming only makes reference to the long-term warming (temperature increase) of the planet observed since 1990 mainly as a result of the increase greenhouse gasses, etc. (National Aeronautics and Space Administration [NASA], n.d.b).

According to IPCC (2014) "Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century".

Greenhouse gases (GHG) are defined as the gases that trap heat in the atmosphere and consequently causes the greenhouse effect. According to the U.S. EPA (2019), main GHGs are Carbon Dioxide (CO_2) mainly produced by burning fossil fuels; Methane (CH_4) emitted during the production coal, natural gas, and oil and from livestock and agricultural practices; Nitrous Oxide (N_2O) emitted during agricultural and industrial activities; and fluorinated gases emitted from several industrial processes. Figure 3.1 presents the GHG emissions share in the United States.

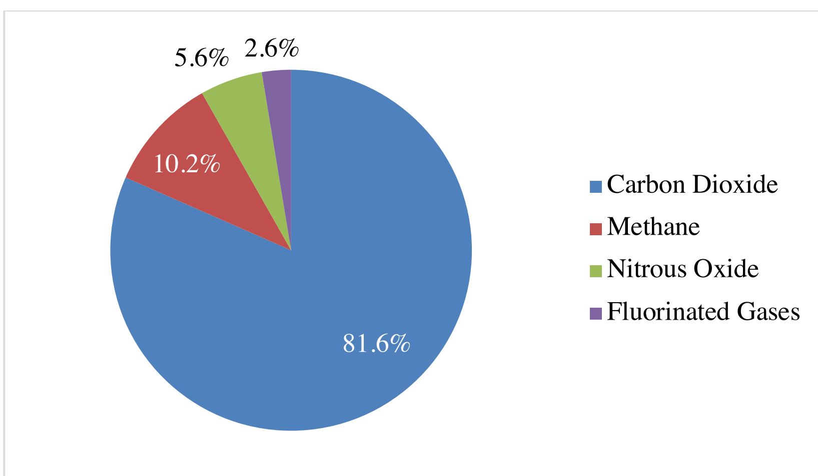


Figure 3.1: U.S. Greenhouse emissions share from 1990 to 2007. Source: U.S. EPA. *"Inventory of U.S greenhouse Gas Emissions and Sinks: 1990-2017"* (2019)

When compared the world and the United States in GHG emissions by economic sector, both are leaded by the electricity production sector. However, it is important to mention that transportation sector in the United States produces equal emissions as the electricity sector. On the other hand, agriculture sector is second GHG emitter. Figure 3.2 presents the GHG emissions shares per sector in the United States and the world.

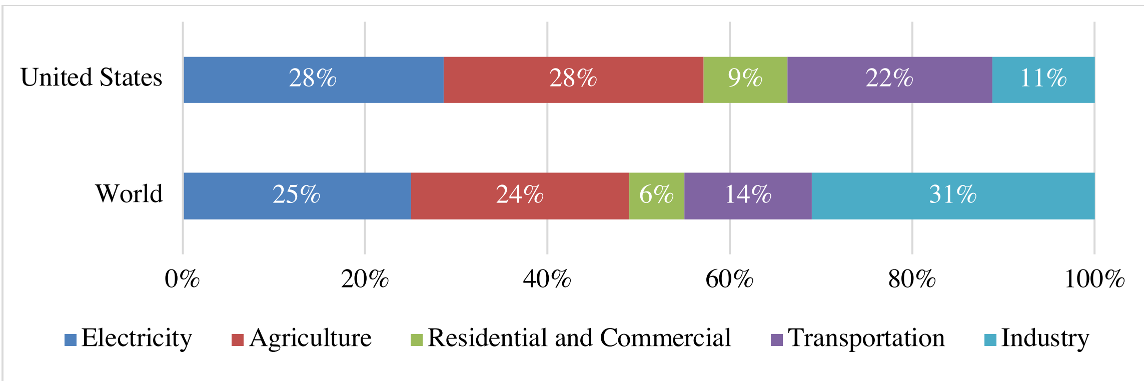


Figure 3.2: Greenhouse emissions share per sector in the United States and the world in 2016. The industry sector includes emissions related to energy not associated to electricity. Source: U.S. EPA. *"Greenhouse Gas Emissions"* (2016)

Residential and commercial sector emissions presented in Figure 3.2 does not includes the emissions related to electricity consumption. Electricity consumption emissions are included in the electricity sector. Taking in consideration both sectors, buildings represented around the 40% emissions in the United States (U.S. EIA, 2017). Urban areas account for the 70% of the GHG emissions in the world when compared to rural areas (Deetjen, Conger, Leibowicz, & Weeber, 2018).

As stated before, anthropogenic activities are considered as the main reason of climate change and the recent global warming (E.g. GHG emissions due to burning of fossil fuels). Currently, climate change causes are a topic highly debated in the media by politicians, citizens, and Scientifics. Around 97% of the published scientific papers addressing climate change and global warming agrees it is happening and anthropogenic activities are the main reason (NASA, 2019).

On the other hand, a Yale University study (Marlon, Howe, Mildenberger, Leiserowitz, & Wang, 2015) states that only 70% of the U.S. population believes that global warming is happening and the 54% that it is caused mostly by human activities. For the Austin-Round Rock MSA, the same study affirms that the MSA's population is slightly more aware of global warming. 77% of the population believes that global warming is happening and 63% that it is caused by human activities.

Some climate change effects are visible today but are expected that global temperatures will rise due to human activities. Also, the effects are different depending on the region. According to the NASA (n.d.a), some long-term climate change effects are temperature increase, longer frost-free seasons, changes in precipitation patterns, more droughts and heat waves, hurricanes will become stronger and more intense, sea level rise, and an ice-free arctic. Annually, billions of dollars and thousands of lives are lost due to unexpected disasters. Climate change is affecting environmental systems and puts at risk human society in several political, economic, and social aspects.

3.2. IPCC Emissions Scenarios

The IPCC considering that GHG emissions are one of the main causes of climate change, published the Special Report on Emissions Scenarios in 2000. The report contains different GHG emissions scenarios used for climate change projections. The scenarios were used in the IPCC Third Assessment Report and the IPPC Fourth Assessment Report published in 2001 and 2007 respectively. In 2014, the special report was supplanted by the Representative Concentration Pathways used in the IPCC Fifth Assessment Report.

GHG emissions scenarios are based on different driving forces such as demographic development, technological change, and socio-economic development (Nakićenobić et.al., 2000). The relationship between the different driving forces are described in different storylines. The report includes four storylines and six scenario groups resulting in forty emission scenarios. The storylines names are A1, A2, B1, and B2.

Storyline A1 describes a rapid economic growth, a population peak in the middle of the 21st century, and a rapid development of new technologies. Also, storyline A1 is the only dived on scenario groups, A1F1, A1T, and A1B. Scenario groups are based on alternatives of the energy system. For example, A1F1 is a fossil fuel intensive scenario, A1T1 a scenario without fossil fuels, and A1B is a balanced scenario.

Storylines A2, B1, and B2 only are divided into one scenario group. A2 describes a heterogeneous world where global population growths continuously, economic development is regional oriented, and technological change is slower. B1 includes the same population growth as A1 storyline but describes rapid changes in economic structures, reductions in material intensity, and the introduction of clean and efficient technologies. Finally, B2 is focused on regional levels following continuous population growth, medium economic development, and slow technologic development.

Figure 3.3 presents the different carbon dioxide emission scenarios projections. Emissions in scenarios A1F1 and A2 are considered high, A1B and B2 moderated, and A1T and B1 low. In this thesis, for the modeling and simulation process are used the A1B, A2, and B1 scenarios. Data is obtained from the Meteonorm software. Figure 3.4 presents the surface temperature projected for the different scenarios used in the simulation process.

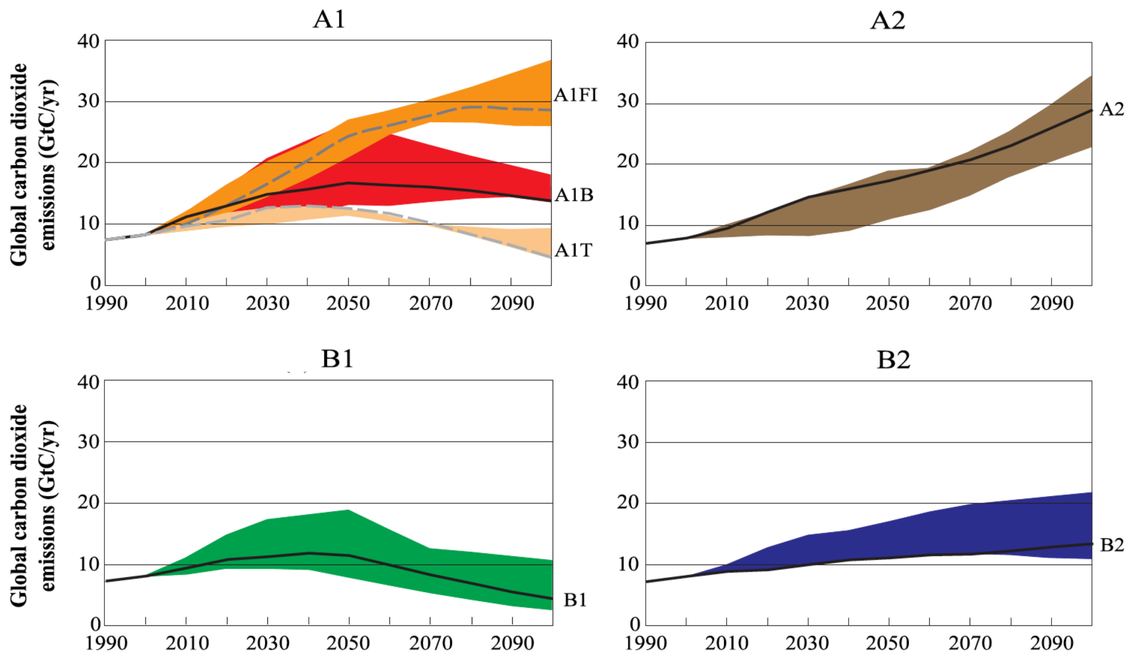


Figure 3.3: Annually global carbon dioxide emissions scenario projections. Source: Nakicébonić et.al. *"IPCC Special Report Emissions Scenarios"* (2000)

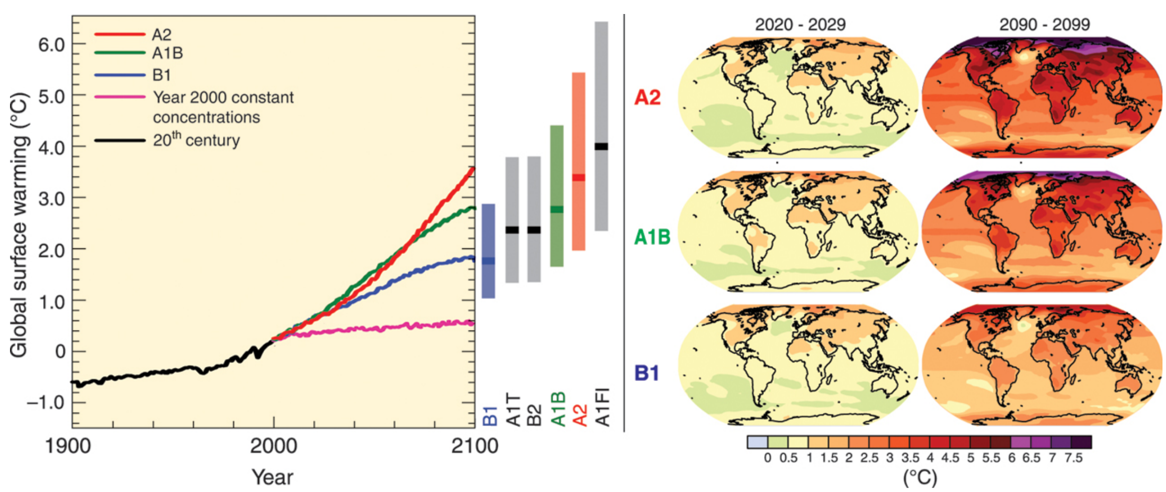


Figure 3.4: Temperature change projections for scenarios used in the simulation process. Source: IPCC. *"Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change"* (2007)

In 2014, Representative Concentration Pathways (RCP) replaced the Special Report on Emissions Scenarios. RCPs are based on the amount of GHG emissions and are labeled according to the possible range of radiative forcing in the year 2100. GHG emissions are expected to peak between 2010 and 2020 for RCP2.6, around 2040 for RCP4.5, and around 2080 for RCP6. For RCP8.5. is expected a continuous growth rate for the GHG emissions (IPCC, 2014). Figure 3.5 presents the carbon dioxide emissions projections for the different RCPs and temperature change for the best and worst scenarios.

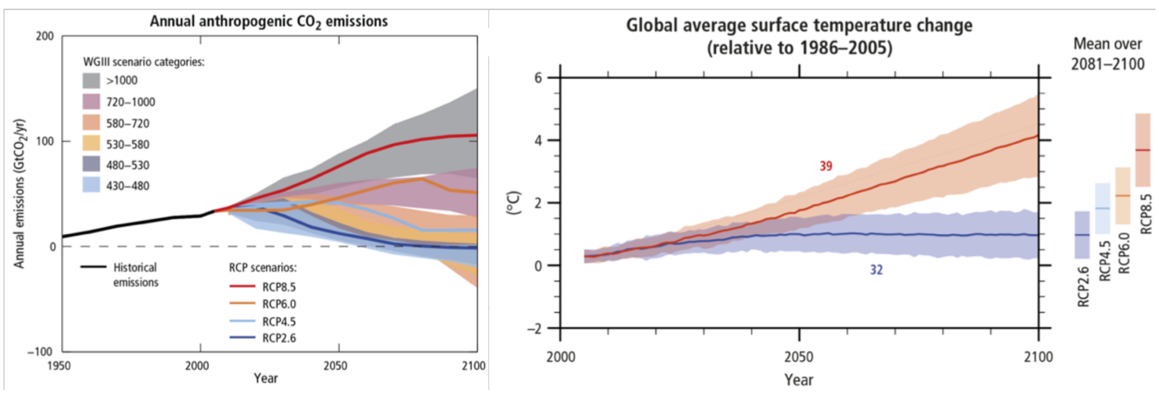


Figure 3.5: Annual anthropogenic carbon dioxide emissions and temperature change projections. Source: IPCC. *"Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change"* (2014)

3.3. Climate Change in Texas and Austin

According to the U.S. Global Change Research Program (USGRP) (2018), in Texas region is expected, as a consequence of climate change, an increase in average temperatures and the frequency and intensity of the extreme heat events. For example, in comparison to the 1976-2005 temperature average, by the mid-21st century is expected a temperature increase between 2ºC and 2.8ºC and for the late century between 2.4ºC and 4.6ºC. Also, it is expected around 30 to 60 additional days with temperatures above 37.7ºC. Figure 3.6 presents a map with the number of days with temperatures above 100ºF or 37.7ºC.

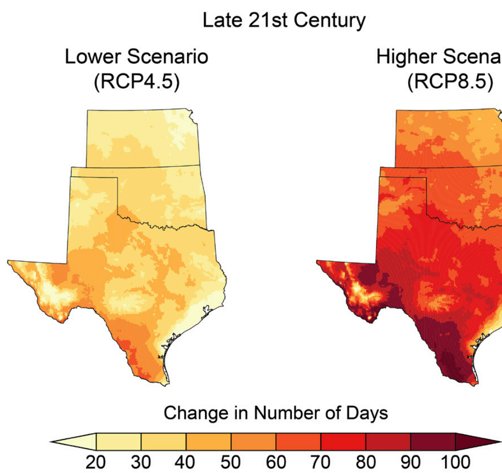


Figure 3.6: Increase of days with temperatures above 37.7ºC in the Southern Great Plains region. Source: USGCRP. "Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II" (2018)

In 2014, Hayhoe presented a climate change report for the Austin area using two RCPs as climate change scenarios, RCP4.5 (Lower scenario) and RCP8.5 (Higher Scenario). The report projected several changes such as the increase in annual and seasonal average temperatures, changes in annual average precipitation, increase in the frequency of extreme temperatures and precipitations, and drought conditions in summer due to hotter weather.

Historically, cold nights (below 32ºF or 0ºC) occur on an average of 15 times per year but are projected to occur between 4 to 7 times per year at the end of the century. Warm nights (over 80ºF or 26.6ºC) are rare because only occur twice every ten years but are expected to occur between 17 to 85 times per year at the end of the century. Figures 3.7 and 3.8 presents the projections for cold nights and warm nights respectively.

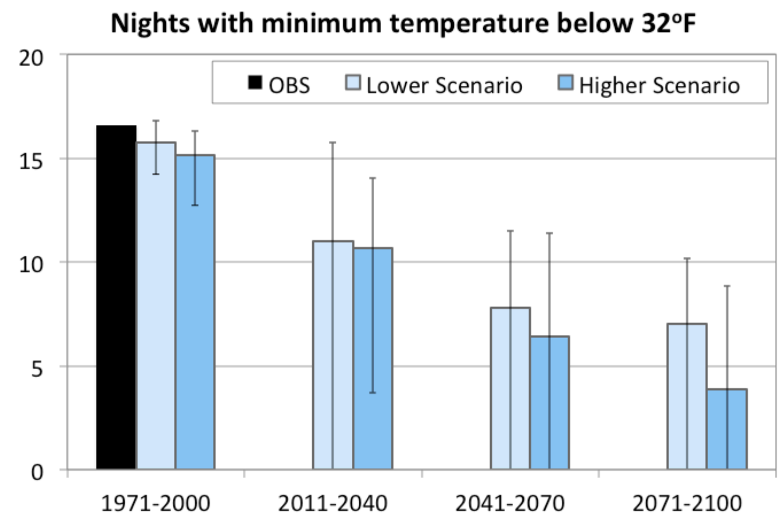


Figure 3.7: Nights with temperatures below 32ºF (0ºC). Source: Hayhoe, K. "Climate Change Projections for the City of Austin" (2014)

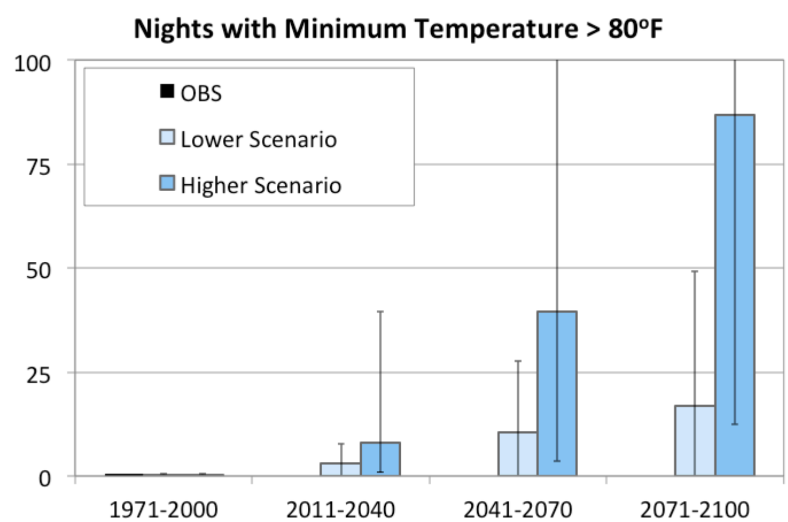


Figure 3.8: Nights with temperatures below 32ºF (0ºC). Source: Hayhoe, K. "Climate Change Projections for the City of Austin" (2014)

By the end of century summer, maximum temperatures are projected to increase between 4ºF to 9ºF (2.2ºC to 5ºC). Historically, average hot days (over 100ºF or 37.7ºC) are 13 per year but are expected to increase between 35 to 80 more days per year. Finally, very hot days (110ºF or 43.3ºC) are projected to increase from 2 times to around 20 times per year. Figures 3.9, 3.10, and 3.10 presents the summer maximum temperature, hot days and very hot days projections respectively.

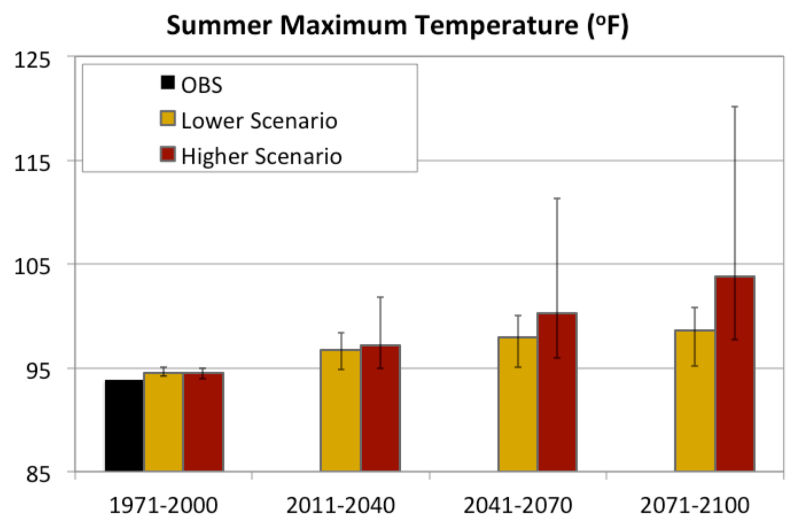


Figure 3.9: Summer maximum temperature projections. Source: Hayhoe, K. *"Climate Change Projections for the City of Austin"* (2014)

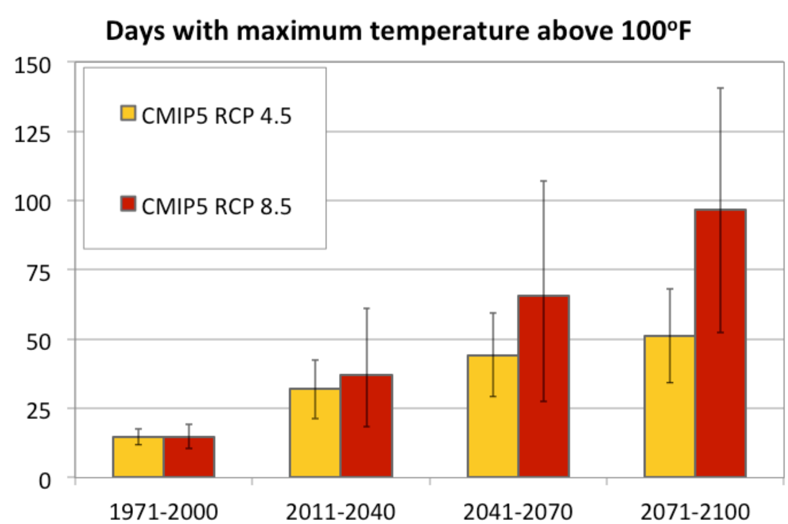


Figure 3.10: Summer maximum temperature projections. Source: Hayhoe, K. "Climate Change Projections for the City of Austin" (2014)

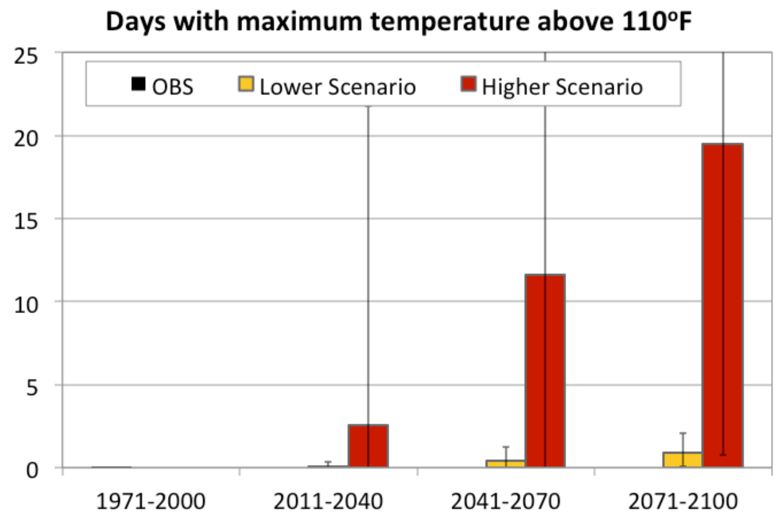


Figure 3.11: Summer maximum temperature projections. Source: Hayhoe, K. "Climate Change Projections for the City of Austin" (2014)

Chapter 4: Building Energy Codes and Green Building Certifications

In this chapter are explained the different building energy codes and green building certifications used for the simulation process of this research. The simulation process will use three different scenarios that are considered in two postures. First, the mandatory posture includes the scenario for mandatory building energy codes for both residential and commercial/multi-family buildings in the State of Texas. On the other hand, for the voluntary posture are included two scenarios for voluntary green building certifications, the Leadership in Energy and Environmental Design (LEED) certification and the Austin Energy Green Building certification.

4.1. Mandatory Building Energy Codes

According to the U.S. Energy Information Administration (U.S. EIA, 2018d) residential and commercial buildings in Texas represented 23.5% of the energy used in the state. Building energy codes set the minimum efficiency of new and renovated buildings in order to increase the energy efficiency resulting in significant savings for the state and country economy.

Also, the reduced energy demand in buildings can be associated with less environmental impact, fewer greenhouse emissions and reduced dependency of fossil fuels. The U.S Department of Energy (U.S. DOE, 2016) projects that building energy codes will contribute to save $126 million, avoid 841 MMT of CO_2 emissions, and 12,82 Quads of primary energy in the whole country from 2010 to 2040.

The State of Texas set different mandatory building energy codes according to the type of building. For the case of residential buildings is required the used of the 2015 International Residential Code (2015 IRC) and for commercial and multi-family buildings, the 2015 International Energy Conservation Code (2015 IECC). The Texas State Energy

Conservation Office (SECO) is in charge to authorize the adoption of the different building codes. SECO decided to adopt codes published by the International Code Council (ICC). The Energy Systems Laboratory is in charge of the review of the codes' content and sends comments to SECO to adapt the codes to the Texan context.

4.1.1. Residential: 2015 International Residential Code

Since September 1, 2016, SECO adopted Chapter 11 of the 2015 International Residential Code (2015 IRC) as the state's residential energy code (U.S. DOE, 2018a). Chapter 11 includes all the energy efficiency measures that a single unit or multifamily with three stories or fewer must comply for design and construction. The main intent of Chapter 11 (International Code Council [ICC], 2015a) is "to regulate the design and construction of buildings for the effective use and conservation of energy over the useful life of each building."

2015 IRC determines some project specifications such as insulation materials and their R-values, fenestration U-factors and Solar Heat Gain Coefficients (SGHC), mechanical system design criteria, equipment controls, system controls, equipment dimension, equipment efficiency, among others.

On the other hand, the Texas legislature approved the Energy Rating Index (ERI) as an alternative compliance path for the 2015 IRC. The index ranges from 0 to 100 where 0 represents net-zero energy and 100 the efficiency of a home built using the 2006 International Energy Conservation Code (The South-Central Partnership for Energy Efficiency as a Resource [SPEER], n.d.). Maximum ERI scores allowed by the Texas Health and Safety Code §388.003 are based on the project's Climate Zone (CZ).

In order to increase energy efficiency maximum ERI score allowed changes over time. Austin is located in the CZ2A where the maximum allowed ERIs are 65 for projects submitted from September 1, 2016, to August 31, 2019; 63 from September 1, 2019, to August 31, 2022; and 59 on or after September 1, 2022.

4.1.2. Commercial and Multi-family: 2015 International Energy Conservation Code

For the case of commercial and multi-family buildings, since November 1, 2016, SECO adopted the 2015 International Energy Conservation Code (2015 IECC) as the energy code for use in residential multi-family, commercial, and industrial buildings (Texas Comptroller of Public Accounts, n.d.). In Austin, the City of Austin Ordinance No. 20160623-099 adopted the 2015 IECC with local amendments.

The scope of the code includes the specification of materials and their R-values, fenestration U-factors and SGHCs, mechanical system criteria, equipment size, equipment efficiency, economizer description, lighting design, air sealing, daylight specifications, equipment controls, among others (ICC, 2015b).

4.2. Voluntary Green Building Certifications

Green buildings are considered structures that are environmentally responsible throughout the whole building's life-cycle including design, construction, operation, and deconstruction (U.S. EPA, n.d.). Buildings reduce their environmental impact by the efficient use of energy, water use reduction, use of sustainable materials, increase the comfort of the occupant, and waste reduction (U.S. Green Building Council [USGBC], 2011).

The green building movement is supported and promoted by several non-profit, non-governmental, and governmental organizations. There exist dozens of green building certifications adapted to a building type or a region. For example, the U.S. Green Building Council (USGBC) developed the LEED certification, the Living Future Institute created the Living Building Challenge, the Building Research Establishment published the Building Research Establishment Environmental Assessment Method (BREEAM), the City of Austin conceived the Austin Energy Green Building certification, etc.

Certifications are voluntary and usually are required to be adopted by the project team since the design phase. After the project is finished, it is required to submit the project documentation to be reviewed by a third-party organization (usually the organization that developed the certification). For this thesis, LEED certification and the Austin Energy Green Building certification are used for the modeling and simulation process.

4.2.1. Leadership in Energy and Environmental Design

The Leadership in Energy and Environmental Design (LEED) certification is a voluntary green building certification program created to identify, assess, and implement environmental strategies for green buildings design, construction, and operation (USGBC, 2013). It was developed by the USGBC in March 2000, and since then there have been existed more than one-hundred thousand projects registered in 167 countries (USGBC, 2016).

LEED certification can be used for different building types such as residential, commercial, healthcare facilities, schools, hospitality, etc. Depending on the project type a different LEED framework should be used. For example, for a new construction building can be used the Building Design and Construction (BD+C) framework, for a new construction of a commercial interior the Interior Design and Construction (ID+C), for a building retrofit the Buildings Operations and Maintenance (O+M), for a land development project the Neighborhood Development (ND), and for a single-family unit the Homes framework (USGBC, n.d.).

In order to certify a building, every project must comply with the different prerequisites and obtain at least 40 points of the 100 available and distributed across the different credit categories. There exist four certification levels: certified (40-49 points), Silver (50-59 points,) Gold (60-79 points), and Platinum (80 points and above). The different credit categories are Location and Transportation, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Material & Resources, Indoor Environmental Quality, Innovation, and Regional Priority. For the modeling and simulation process of this thesis are only considered the Building Energy Performance requirements of the Neighborhood Development framework.

For all buildings excluding low-rise residential, the Minimum Building Energy Performance prerequisite requires to comply with the prescriptive provisions of the ANSI/ASHRAE/IESNA Standard 90.1-2010. The standard includes provisions for the heating, heating, ventilation, and air conditioning system (HVAC), building envelope, lighting, power, and service water heating. For the HVAC and service water heating, it is required to comply with the ASHRAE 50% Advanced Energy Design Guide depending on the project type (USGBC, 2013). In the case of low-rise residential buildings is required to comply with the mandatory measures of ENERGY STAR for Homes version 3 (USGBC, 2018).

To earn points, the Optimize Building Energy Performance credit requires to comply with the ASHRAE 50% Advanced Energy Design Guide depending on the project type for building envelope, lighting, and power specifications. In the case of low-rise residential is required to reduce energy consumption by 20% in comparison to the initial energy budget (USGBC, 2013).

4.2.2. Austin Energy Green Building

The Austin Energy Green Building (AEGB) certification was developed in 1991 by the City of Austin. It is considered the first green building rating system in the United States (Austin Energy, 2016a). The rating system can be applied to different building types such as single-family units, multifamily buildings, and commercial buildings. Actually, there exist more than 20 million square feet of commercial buildings, 15,000 single-family homes, and 34,000 multifamily dwelling units rated by AEGB in the Austin area (Austin Energy, 2018).

AEGB certification is based on basic requirement and voluntary measures grouped in different credit categories such as Integrated Design, Site, Energy, Water, Indoor Environmental Quality, and Education & Equity. The project can earn points depending on the voluntary measures applied and achieve a certification level. The levels are 1 Star (comply with the basic requirements), 2 Stars (35-44 points), 3 Stars (45-54 points), 4 Stars (55-74 points), and 5 Stars (75 points and above).

For commercial buildings, as a basic requirement, AEGB requires to comply with the 2015 IECC - Section C406.2 and reduce building interior lighting power by 15%. To increase energy efficiency and earn points, as a voluntary measure the AEGB requires to implement several measures for the building envelopes, daylight controls, and water heaters included in the AEGB 2016 Commercial Rating Guidebook.

For multifamily buildings, the AEGB 2016 Multifamily Rating Guide as a basic requirement recommends several prescriptive requirements. For example, a maximum U-value of 0.35 and SGHC of 0.25 for glazing, maximum R-value of R-13+3 c.i. for wood frame exterior walls, not exceed 0.6 W/sq.ft. for overall lighting power density, 15 Seasonal Energy Efficiency Ratio (SEER) for split mechanical systems, among others. In the case of voluntary measures, the guide requires to improve the basic requirements for cooling and heating equipment efficiency, water heaters, interior and lighting, and appliances.

Finally, for single-family units, the AEGB 2016 Single Family Rating Guide requires for basic requirements a maximum ERI value of 59, a 15 SEER cooling equipment, and insulation that meets 2015 IECC and ENERGY STAR Grade 1 requirements, and ENERGY STAR rated appliances. In the case of voluntary measures is recommended to install high-performance systems including but not limited to cooling, heating, water heating, and appliances.

Chapter 5: Urban Building Energy Modeling

5.1. Urban Building Energy Modeling Concept

In order to estimate energy demands by building, analyze different future scenarios, and propose interventions, cities can take advantage of modeling and simulation available tools. Analysis can be realized by the modeling and simulation of stand-alone buildings for individual building design level or the developing of building stock energy models to estimate the urban energy consumption by end use (Howard et al., 2012). The last method requires to extrapolate data from the status quo and is less useful for the analysis of future scenarios (Cerezo, 2017).

Also, for the urban scale, other tools to analyze a wide range number of buildings at the same time using statistical analytical methods to estimate the energy demand of each building is being developed. This method is not only being capable of analyzing the status quo of the area of interest but also a future scenario based on, retrofit, urban form change, densification, climate change, construction set change, among others. Urban Building Energy Models (UBEM) applies physical models of heat and mass flows to estimate energy consumption and indoor/outdoor environmental conditions for groups of buildings representing each building as a dynamic thermal model (Reinhart & Cerezo, 2016).

UBEMs are expected to be an important tool for urban planners, utility companies, and decision makers to explore energy supply-demand scenarios. For example, city managers can evaluate and prioritize energy conservation measures for a city-scale retrofit analysis (Chen, Hong, & Piette, 2017). The use of UBEMs reduce the dependence on metered energy demand data but requires more building information. The creation of a UBEM model requires the specification of multiple aspects of the built environment. This includes but is not limited to the geometric and non-geometric properties of the building, and climate conditions.

5.2. Data input

For the data input, it is necessary to obtain three datasets: climate, building geometry parameters, and building non-geometry parameters. These datasets are typically used for stand-alone building energy models but in this case, the datasets, especially the non-geometry parameters, should be carefully analyzed due to the broad range of buildings that are analyzed at the same time.

A typical meteorological year (TMY) file is a standard dataset used for climate analysis and building simulation and is available for more than 2100 locations in the USA and the world in the U.S. Department of Energy, EnergyPlus website (U.S. DOE, 2018b). In the case of this thesis, climate dataset was obtained from the Meteonorm software including actual and climate change scenarios.

TMY files usually include information for a typical year of several environmental variables such as dry bulb temperature, solar radiation, relative humidity, and wind speed. The TMY dataset includes a .epw file to be used in EnergyPlus software environments and allows the modeler to perform the simulation. For the purposes of this thesis the Austin-Austin Airport climate file was used.

For the building geometry data, a UBEM requires at least 3D shapes or “massings”. The information can be obtained from traditional two-dimensional CAD files and Geographic Information System (GIS) databases previously produced by municipal planning departments. GIS shapefiles are capable to store the building height and terrain height values making the “massing” task easier for the modeler.

Finally, the building non-geometry parameters dataset must include data about materials and construction information, systems, and occupant operations parameters. Data collection and characterization for large urban scale projects can be impractical because it represents a large amount of time used for the task. Also, the uncertainty of usage schedules and occupancy rates are unavoidable, therefore non-geometry datasets represent one of the main sources of error.

Some authors recommend using building archetypes to represent buildings according to age, shape, use, and installed systems. To understand how to influence the non-geometric building and occupant factors, the modeler must characterize the building archetypes. The parameters are defined by the simulation tools, the modeling approach, and the zoning simplification (Reinhart & Cerezo, 2016). In the case of the modeling approach it could be steady state or dynamic and for the case of the zoning, single zone or multi-zone.

5.3. Software Used

For UBEM analysis, some of the currently available tools are the Urban Modeling Interface (UMI) developed by the Sustainable Design Lab at the Massachusetts Institute of Technology (MIT); CitySim developed by the Swiss Federal Institute of Technology in Lausanne (EPFL); the City Building Energy Saver (CityBES) developed by the Lawrence Berkeley National Laboratory; and SimStadt developed by the Energy and Geo-informatics departments of the Stuttgart Technology University of Applied Sciences. The software used in this thesis for the modeling and simulation process was UMI.

The UBEM analysis workflow will differ depending on the type of simulation, the simulation tools, and the detail of the UBEM. UMI follows a workflow that includes the use of a shapefile to obtain GIS data, imported it to Rhinoceros 3D, then the massing model is finished in Rhinoceros 3D, the data for the model is introduced in UMI, and EnergyPlus is used as the dynamic energy simulation engine. Software versions used for this thesis were for UMI, version 2.0 and for Rhinoceros 3D, version 5.0.

As explained before, weather datasets were obtained from the Meteonorm software. The software provides irradiation data from every place on Earth, global climate databases from more than 8,000 weather stations, temperature, climate change scenarios, and other weather parameters. Currently, Meteonorm is distributed by the Meteotest AG company based in Switzerland. The version used for this thesis was 7.3.

5.4. Uncertainty and Previous Study Cases

It is expected to see different results from the UBEM in comparison with measured results due to uncertainties regarding occupant behavior, infiltration rates, etc. However, several previous studies presented error ranges between 1% and 19% for the total Energy Use Intensity (EUI) and 5% to 20% for heating loads. Error levels are close to the maximum allowed by the ASHRAE Guideline 14-2002. Usually in stand-alone building simulations uncertainty is solved using calibration methods based on metered data but for the case of UBEM, there exists very low research about large-scale calibration methods.

There exist several previous UBEM study cases using different simulation tools. Some interesting examples are the Boston citywide energy model by the sustainable design lab at MIT and the Boston Redevelopment Authority (BRA), the northeast San Francisco retrofit analysis using CityBES, and the simulation of Alt-Wiedikon neighborhood in Zurich using CitySim. Also, an Intelligent Environments Lab from the University of Texas Cockrell School of Engineering research provided valuable guidance and advice for this project. Research consisted in the analysis of the impact of climate change and envelope retrofit on urban energy consumption (Felkner et. al, 2019), and the urban transformation as mitigation of the impacts of climate change (Felkner, Brown, Vásquez-Canteli, & Nagy, 2019).

For Boston, a citywide energy model was modeled and simulated 83,541 buildings using 52 use/age archetypes. The EUI results from the simulation process were compared with the Commercial Buildings Energy Consumption Survey (CBECS) and the Residential Energy Consumption Survey (RECS). The comparison showed an average error between 5% to 20% for most types of buildings. Average EUIs ranged between 87 kWh/m^2 to 679 kWh/m^2. When the results were compared with the total gas and electricity use by zip code, the average absolute error for energy use was 40% (Cerezo, Reinhart, & Bemis 2016).

In the case of the northeast San Francisco retrofit, 940 buildings were analyzed using CityBES. The software used simplified datasets including 106 attribute fields, 45 for building characteristics and 61 for energy ordinances. The analysis consisted of finding the best ECM covering three major building systems (HVAC, lighting, and envelope). Results estimated the replacement of existing lighting systems with LEDs is one of the most cost-effective measures. The study used standard efficiency values from California Title 24 and ASHRAE 90.1 to create the prototype buildings, therefore it is interesting to know the error between the prototype and the real building (Chen, Hong, & Piette, 2017).

The simulation of Alt-Wiedikon, Zurich included the analysis of a neighborhood consisting of 123 buildings. Using CitySim, the team simulated the status quo of the neighborhood and a renovation scenario. Several datasets including cadastral maps, buildings register, company census, and a visual survey to complete the physical model. The footprint and average height were imported from cadastral files. The WWR and U-values were resulting from the visual survey and the minimum and maximum set points were set to 21ºC and 26ºC. For this research, building archetypes were not used. For the renovations, interventions were recommended that reduce the heating and cooling demand by 19.5% and 50.1% respectively (Perez, Kämpf, Wilke, Papadopoulo, & Robinson, 2011).

A research was performed for the West Campus neighborhood in Austin analyzing the impact of retrofit under the B1 climate change emission scenario obtained from Meteonorm software. Simulation results presented a considerable increase in energy consumption between the typical mean year and 2040 followed by a steady increase between 2040 to 2100. Retrofit consisted of three different cases, improved wall material, improved glazing, and full refurbishment. The team found that improved glazing is more effective in terms of energy consumption reduction in comparison to an improved wall. Additionally, results presented a considerable increase in energy consumption for cooling. To reduce the impact of climate change in energy consumption is recommended a full refurbishment for the different buildings of the neighborhood (Felkner et. al, 2019).

Chapter 6: Case Study: Mueller Neighborhood, Austin, TX

6.1. Site Description

The Mueller neighborhood is located in the east-central part of Austin. Previously in the area was placed the Robert Mueller Municipal Airport. The Mueller airport started operations in 1930 and it was the first airport that served the Austin-Round Rock MSA. After 59 years of service, in 1999, the airport was decommissioned and replaced by the Austin Bergstrom International Airport. The decommissioning of the airport left vacant an infill area of 711 acres ready to be redeveloped. The city of Austin visualized to replace the airport by a green community and in 1997 hired a design firm to develop a redevelopment master plan for the ex-Mueller airport area. The construction of the neighborhood started in 2004 led by the real estate company Catellus and it is expected to have a market value of around $1.3 billion after the project is completed.

6.1.1. Master Plan

The Mueller neighborhood master plan includes 4.2 million square feet of non-residential development including around 650,000 square feet for retail. Also, there are planned 4,600 residential units distributed in 2,200 apartments, 1,500 single-family houses, and 900 attached houses (Mueller, 2013). In 2017, the master plan was completed by 40% (McCann Adams Studio, 2017).

In the northwest corner of the neighborhood is located a retail center whit some anchor stores such as The Home Depot and Best Buy. Close to the retail center are located the Dell Children's Medical Center of Central Texas and other health centers such as the Ronald McDonald house Also, The University of Texas is developing a 14-acre campus focused into health research. The Austin Independent School District located its performing arts center next to the research campus. Other retail areas in the neighborhood include the market district, the children's museum, several buildings dedicated to restaurants, an H-E-B supermarket, and an under-construction town center.

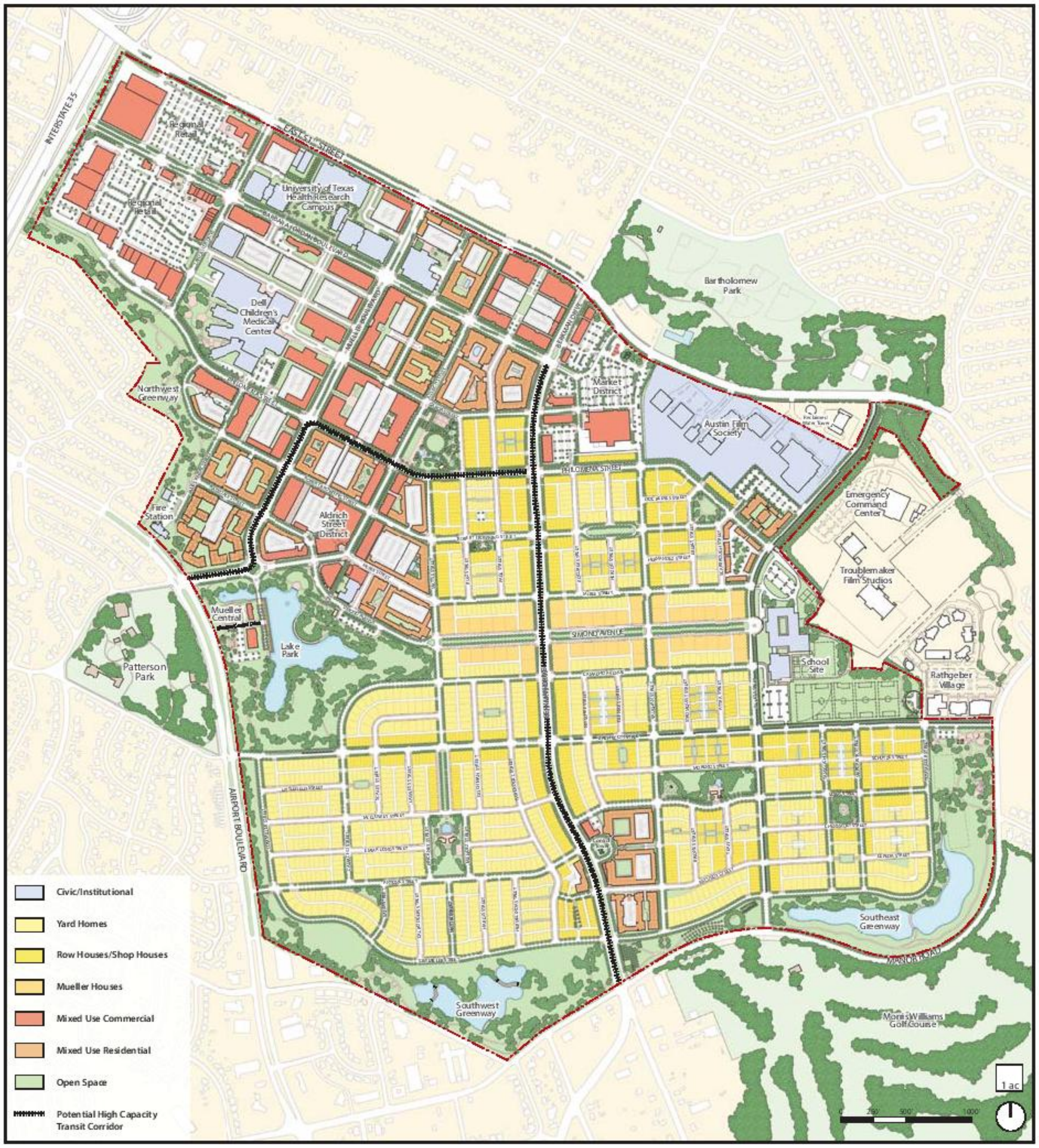


Figure 6.1: Mueller neighborhood master plan. Source: McCann Adams Studio (2017)

From the 711 acres of the entire community area, 140 acres are used as open space for parks and trails (McCann Adams Studio, 2017). Open space includes the Mueller Lake Park (Figure 6.2), the Northwest Greenway, the Southwest Greenway, the Southeast Greenway, the Ella Wooten Park, and the John Gaines Park.

Figure 6.2: Mueller Lake Park. Source: Ng Osorio (2018)

6.1.2 Sustainability

As explained before, the Mueller neighborhood was envisioned to be developed as a green community applying green building and New Urbanism strategies. The main environmental sustainability objectives of the community are to protect the air quality, reduce the urban heat island effect, protect the night sky, and create green buildings. In the case of green buildings, the master plan promotes several green building performance requirements. For example, residential buildings (including single-family) should comply with the guidelines of the Austin Energy Green Building (AEGB) program and achieve a minimum 3-star rating; multi-family buildings should achieve at least the minimum level of the Leadership in Energy and Environmental Design (LEED) certification or at least 2-star under the AEGB program: and for the office, retail, and institutional buildings the requirement is the same as the multi-family buildings (McCann Adams Studio, 2017).

In 2016, Mueller achieved the LEED for Neighborhood Development Stage 3 Gold certification making it the largest neighborhood to achieve the Stage 3 certification in the world (McCann Adams Studio, 2017). In 2018, Mueller community claimed the achievement of several sustainable elements such as 27 percent indoor water consumption, 23.1 million kWh of energy saved annually, 85% of construction waste diverted from landfills, reuse of former airport structures, one of the highest concentration of rooftop solar panels and electric vehicles in the country, landscape irrigation with reclaimed water, and the use of native and adaptive species in landscape (Mueller, 2018).

Also, the Mueller community promotes other sustainable strategies to reduce environmental impact and increase occupant wellness. It is important to mention that Mueller is designed as a pedestrian-oriented community increasing walkability, promoting the use of alternative modes of transportation, and discouraging the use of vehicles. On the other hand, the community is committed to providing affordable housing. Around 25% of the total houses in the neighborhood are considered affordable housing units.

6.2. The Model

The main objective of this research project is to analyze the building energy performance of the Mueller neighborhood under different construction codes and climate change scenarios using Urban Building Energy Modeling (UBEM) tools. The software used for this research was the Urban Modeling Interface (UMI). UMI is a Rhinoceros 3D plug-in. In this case, Rhinoceros 3D was used to model the neighborhood, then the simulation was performed using EnergyPlus.

For the model were identified eight different building uses and they were classified into three different groups to facilitate data management. Building use groups are Residential, Retail, and Offices. The Residential group contains the single-family (detached dwelling units), low-rise multifamily (attached dwelling units and buildings with three stories or fewer), mid/high-rise multifamily (buildings with four stories or more), and hospitality building uses. The Office group includes office and institutional uses. Finally, the Retail group consist only of retail buildings. Healthcare buildings were not included for the simulation process. Figure 6.3 presents the top view of the model and Figure 6.4 the 3D view.

Figure 6.3: Top view of the Mueller neighborhood model. Scale 1:250. Source: modeled by Ng Osorio (2019) using AutoCAD 2018 software

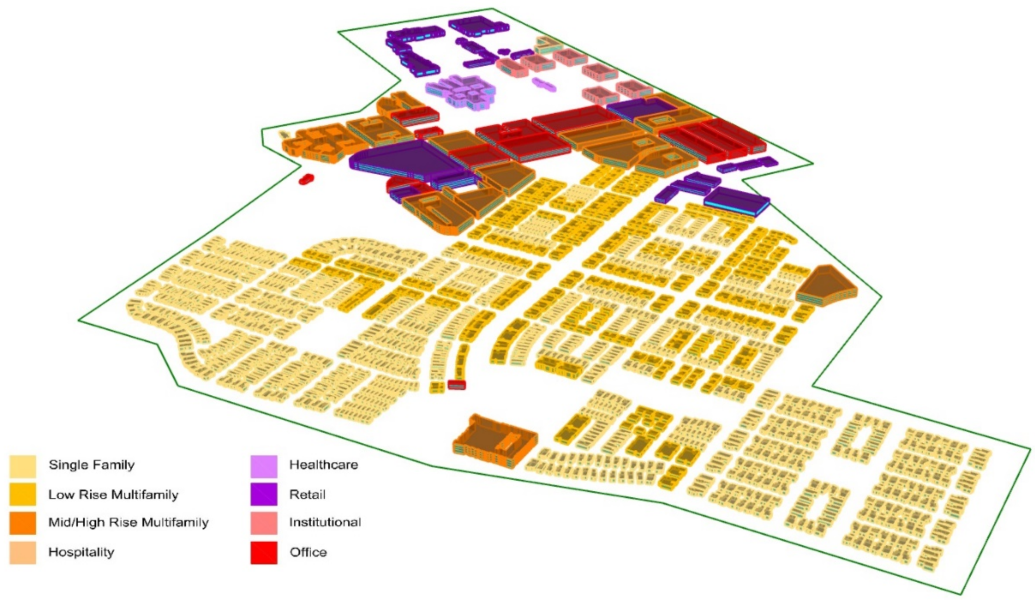
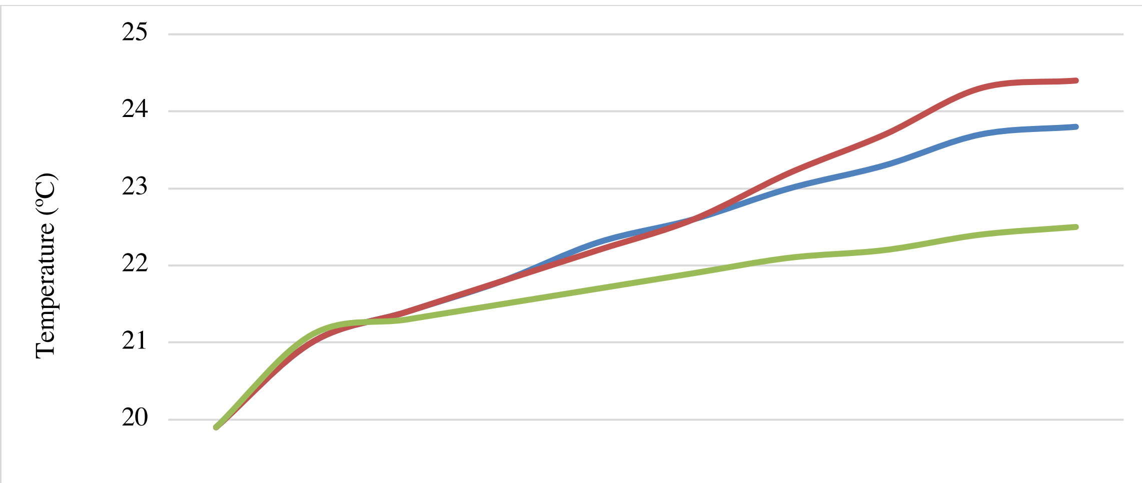


Figure 6.4: Three-dimensional view of the Mueller neighborhood model. Source: modeled by Ng Osorio (2019) using Rhinoceros 3D software

The model consists of 1521 buildings including 1194 single-family, 268 low-rise multifamily, 16 mid/high-rise, 2 healthcare, 5 institutional, 14 offices, 1 hospitality, and 21 retail buildings. Some of the buildings are already build and other are speculative and based on the land use information provided by the master plan (Figure 6.1). All buildings were simulated using the code requirements for every use type. The model not considered any on-site renewable energy production or cooling districts.

6.2.1 Climate Data

For the energy simulation process are used .epw files obtained from Meteonorm software. Files used are based on the Special Report on Emissions Scenarios A1B, A2, and B1. The different tiers of greenhouse emissions are represented in the data used for the simulation. Scenario A2 is considered a high emissions scenario, A1B moderate, and B1 low. From 2020 and 2060, average temperature for the high and moderate emissions scenarios are forecasted to increase at the same rate. Difference between high and low emissions scenarios is 1.9ºC by the end of the 21st century. For the worst-case scenario, the average temperature will increase 4.5ºC in comparison to the average temperature observed between 1990 and 2010. Austin is in the 2A building climate zone according to the American society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Figure 6.5 presents the different annual average temperature change scenarios for the Austin Airport, the climate file for the Austin area.



	1990-2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1B	19.9	21	21.4	21.8	22.3	22.6	23	23.3	23.7	23.8
A2	19.9	21	21.4	21.8	22.2	22.6	23.2	23.7	24.3	24.4
B1	19.9	21.1	21.3	21.5	21.7	21.9	22.1	22.2	22.4	22.5

Figure 6.5: Estimated increase of average annual temperature until 2100 by emission scenario. Source: modeled by Ng Osorio (2019) using Meteonorm software

6.2.2. Design and Construction Scenarios

For this research project, three different construction codes were selected to analyze their building energy performance under the climate change scenarios mentioned in section

6.2.1. The selected construction codes are the International Energy Conservation Code (IECC) and the International Residential Code (IRC) as the state mandatory codes amended by the City of Austin, the voluntary Austin Energy Green Building (AEGB) certification, and the voluntary Leadership in Energy and Environmental Design (LEED) certification. It is important to mention that the main intention of this research is to compare the construction codes mentioned above in a determined existing urban layout, therefore no energy simulations were considered and performed for the state of the art of the neighborhood.

As explained in chapter 4, the 2015 IRC and IECC are the codes that determine the building minimum energy efficiency requirements in the state of Texas. Both codes were amended by the City of Austin Ordinance No. 20160623-099 that regulates the minimum requirements for buildings located in Austin. On the other hand, buildings following the voluntary green building certification requirements, AEGB and LEED, are designed to exceed the energy efficiency requirements of national, state or local mandatory codes.

In the case of the AEGB certification, energy efficiency requirements are based on the IECC. The LEED certification is mainly based on American federal codes such as defined by ASHRAE. It is important to mention that due to the vast international application of the LEED certification, the minimum requirements change depending on the location and it requires to comply or exceed the minimum local regulations. However, for this research this requirement has been ignored, then federal regulations are considered as the base energy efficiency requirements. Also, for both voluntary certification scenarios were created building templates to comply with the minimum requirement for energy efficiency improvement.

All data used for the baseline models were obtained from the official codes and guides. For mandatory codes, the 2015 IECC (ICC, 2015b) was used. For the case of the

LEED certification, the LEED for Neighborhood Development reference guide (USGBC, 2013) and the LEED for Homes reference guide (USGBC, 2018) were used. Finally, for the AEGB certification, the AEGB 2016 Commercial Rating Guidebook (AEGB, 2016a), the AEGB 2016 Multifamily Rating Guidebook (AEGB, 2016b), and the AEGB 2016 Single-Family Rating Guidebook (AEGB, 2016c) were used.

Chapter 7: Results and Findings

In this chapter, the results obtained from the modeling and simulation process are presented and discussed. First, simulation results are presented by emission scenario and building use. In section 7.2 includes an analysis and discussion of the increase of energy consumption per building use and code or standard for the years 2050 and 2100. In final section of this chapter the cooling demand is compared and analyzed.

7.1. Energy Consumption by Climate Change Scenarios

In the following sections are presented the results obtained using the Urban Modeling Interface software applying the methodology already introduced. As explained before, three emissions scenarios were used to obtain the weather files from Meteonorm software. Emission scenarios are B1, A1B, and A2. Results are organized by emission scenario and building use.

7.1.1. Historical Climate Data and other comparable baselines

In order to have a point of reference for this research an energy simulation was performed using the historic climate data for Austin obtained from Meteonorm (Figure 7.1). According to the results obtained for mandatory codes, for the residential use group, mid/high-rise multifamily and low-rise multifamily uses the lower energy per area in comparison to single-family buildings. As explained in chapter 6, for LEED certification were used federal standards as baseline. This explain the closer results between LEED and mandatory codes. 2015 IECC is stricter than ASHRAE 90.1-2010, the baseline code for mid/high-rise buildings seeking a LEED certification.

Results obtained from the energy simulation process can be compared with some energy consumption statistics. For example, the average energy use in a single-family unit is around 68 kWh/m^2/year (City of Austin, 2019), and around 60 kWh/m^2/year for an apartment in a multifamily building (Dataport, 2019).

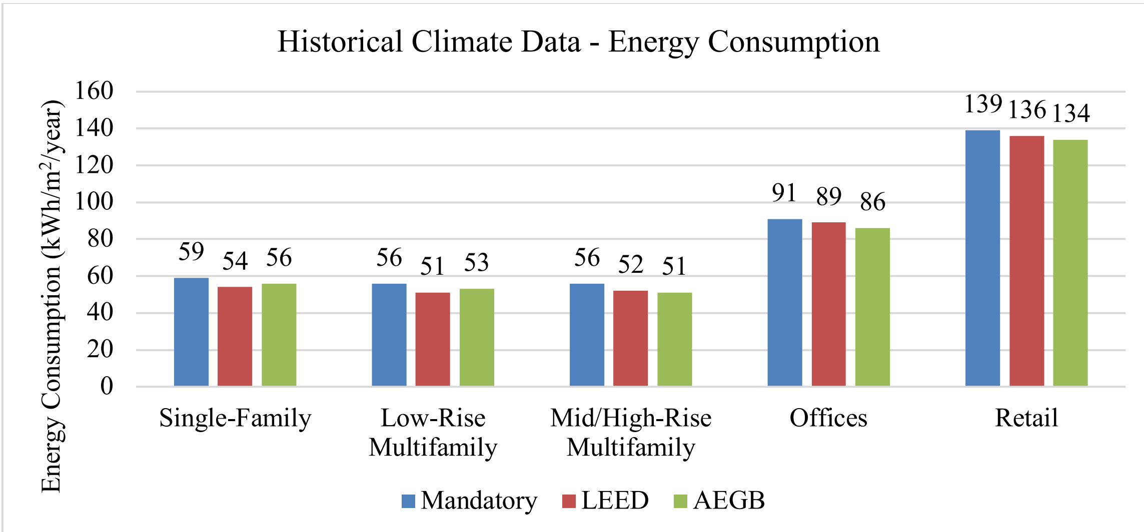


Figure 7.1. Historical climate data energy consumption for the different building use types. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

7.1.2. B1 Emissions Scenario

Among the three emissions scenarios used in this research, the B1 scenario is considered the scenario with the lower projected emissions because assumes continuing economic growth accompanied by a focus on sustainable development (Nakićenobić et.al., 2000). As expected, the increase in energy consumption is lower in comparison to A1B and A2 scenarios. As presented in Figures 7.2, 7.3, 7.4, 7.5, and 7.6, all building types increased their energy consumption.

For all building use types, the mandatory code consumes the most energy per square meter. For example, by the end of the century, it is expected an energy consumption of 66 kWh/m^2/year in single-family buildings, 64 kWh/m^2/year in low-rise multifamily buildings, 64 kWh/m^2/year in mid/high-rise multifamily buildings, 98 kWh/m^2/year in office buildings, and 153 kWh/m^2/year in retail buildings. Figures 7.2 and 7.3 presents the consumption in single-family and low-rise multifamily buildings respectively. In this case, LEED certification measures result in lower energy consumption.

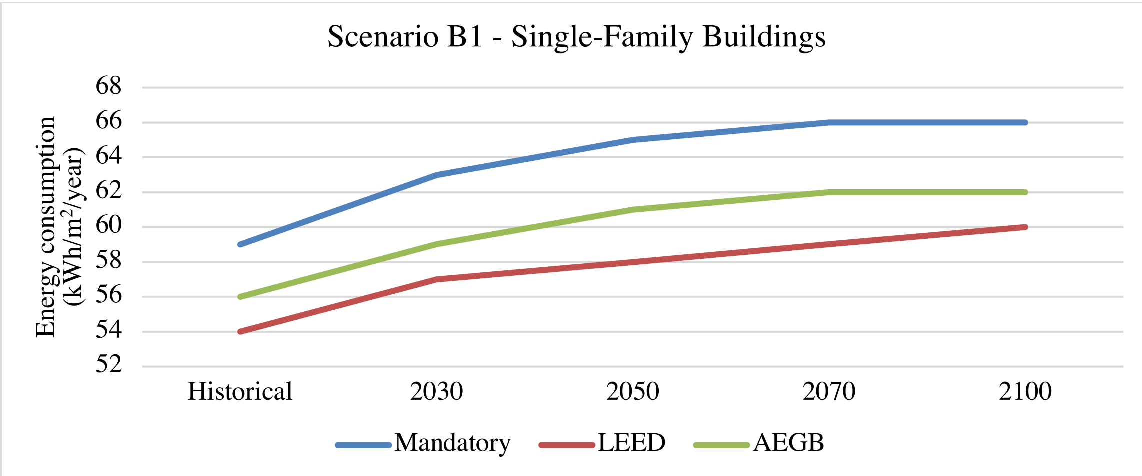


Figure 7.2. Scenario B1 single-family energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

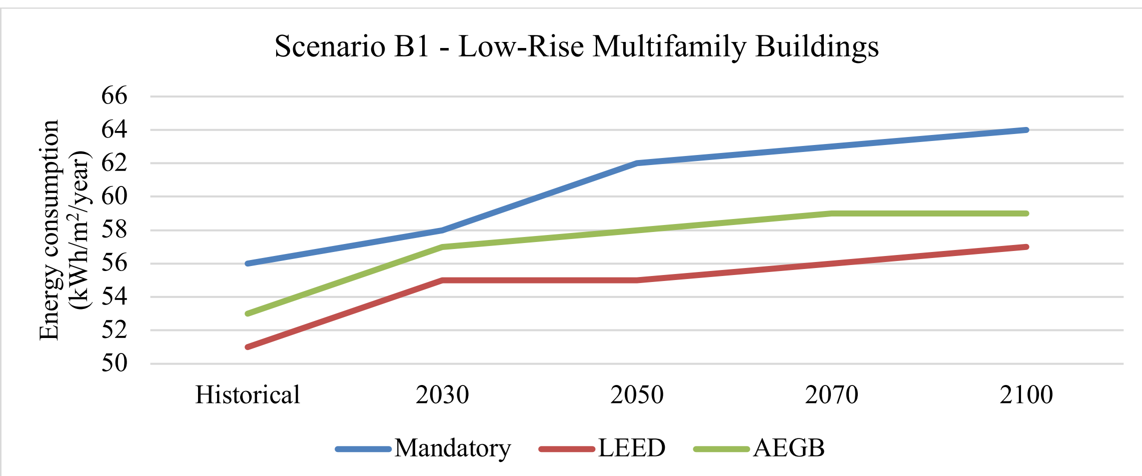


Figure 7.3. Scenario B1 low-rise multifamily energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

According to the results presented in Figure 7.4, LEED and AEGB measures make the most benefits in mid/high-rise multifamily buildings when compared to the mandatory code. In this case, by the end of the century, building energy performance is projected to be around 7 to 8 kWh/m^2/year lower than mandatory code.

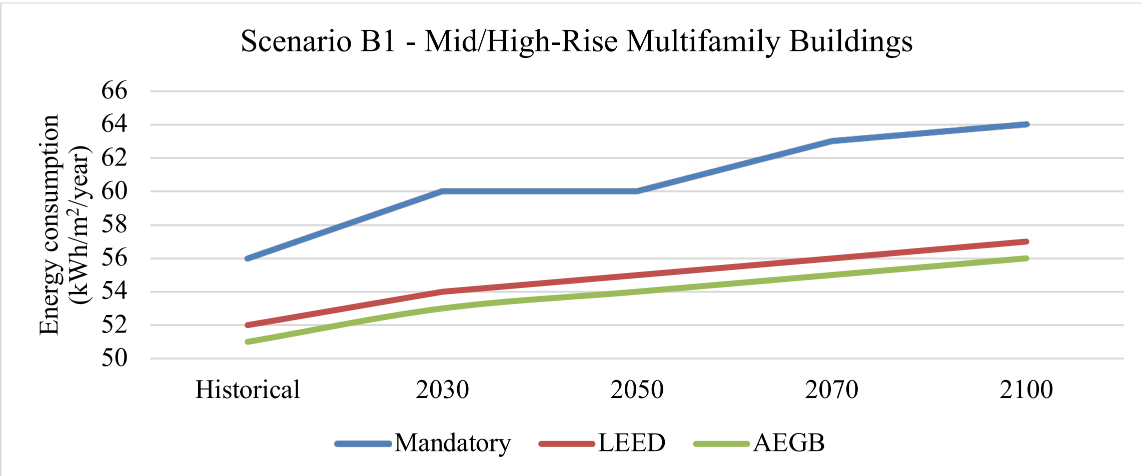


Figure 7.4. Scenario B1 mid/high-rise multifamily energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

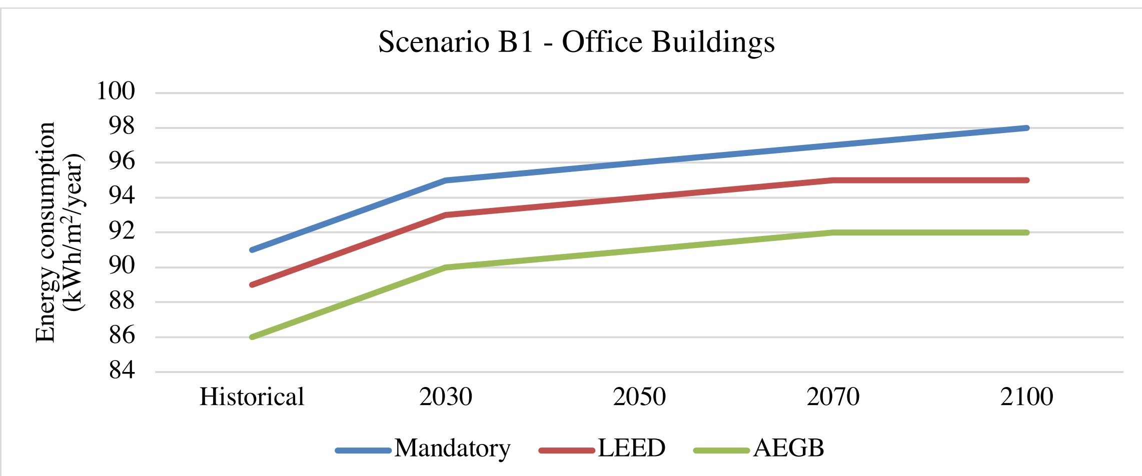


Figure 7.5. Scenario B1 office energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

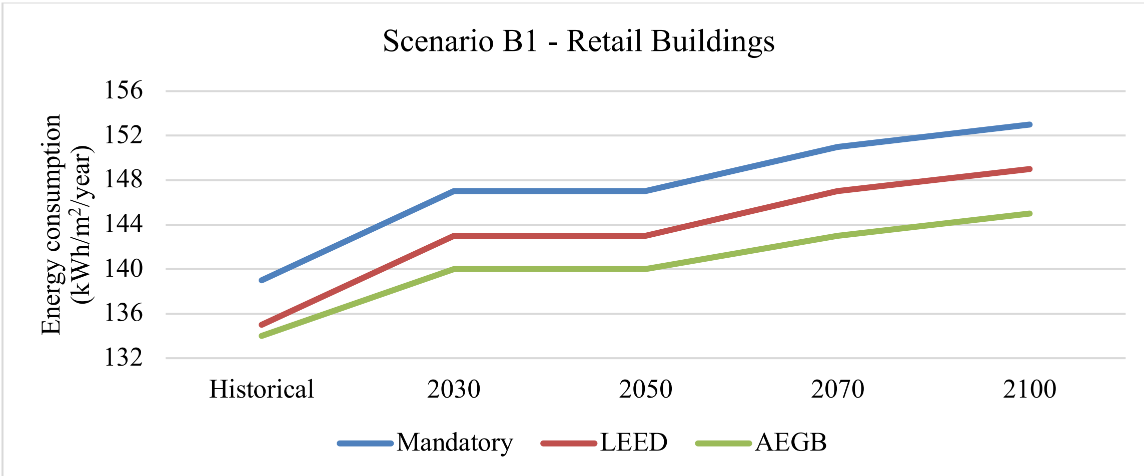


Figure 7.6. Scenario B1 retail energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

Results from Figures 7.4, 7.5, and 7.6 presents that measures selected to comply to AEGB requirements are more restrictive than LEED in large buildings such as mid/high-rise multifamily, offices, and retail. Finally, it is important to mention that in the energy consumption curve slope is lower from 2070 to 2100 due to the low-temperature change between those years in comparison to the other cases.

7.1.3. A1B Emissions Scenario

The A1B emission scenario is considered as a moderate scenario because assumes a rapid economic and growth, balanced energy grid, and rapid technology development that eventually will help to reduce greenhouse emissions (Nakićenobić et.al., 2000). Figures 7.7, 7.8, 7.9, 7.10, and 7.11 presents the energy consumption projected for the B1 emission scenario. Just as the emission scenarios tools, LEED certification measures results in lower energy consumption for single-family (Figure 7.7) and low-rise multifamily buildings (Figure 7.8).

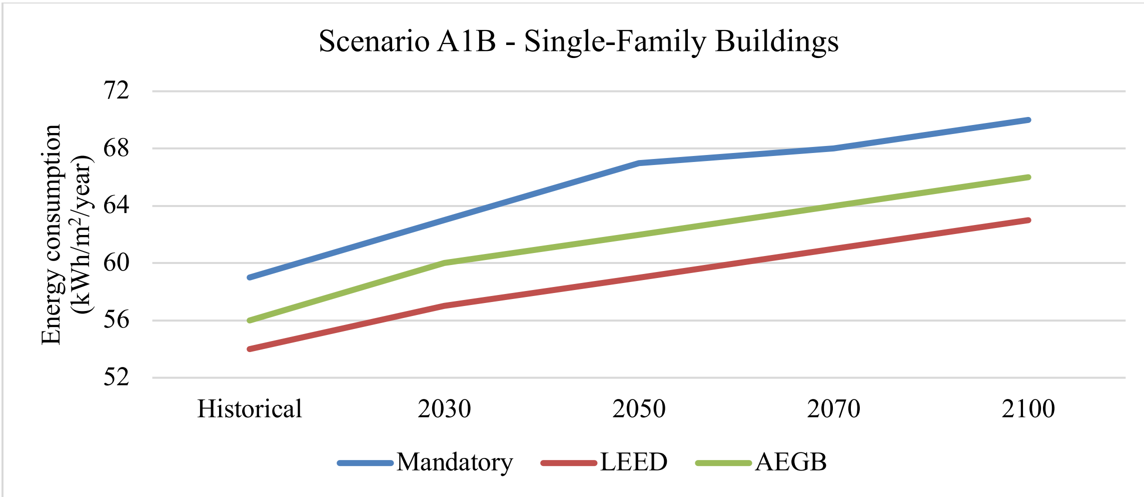


Figure 7.7. Scenario A1B single-family energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

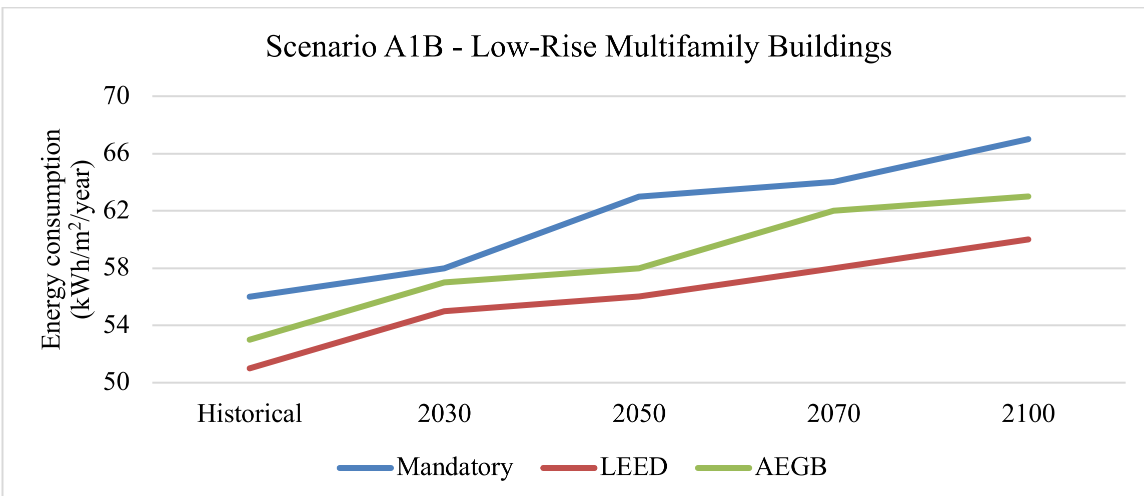


Figure 7.8. Scenario A1B low-rise multifamily energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

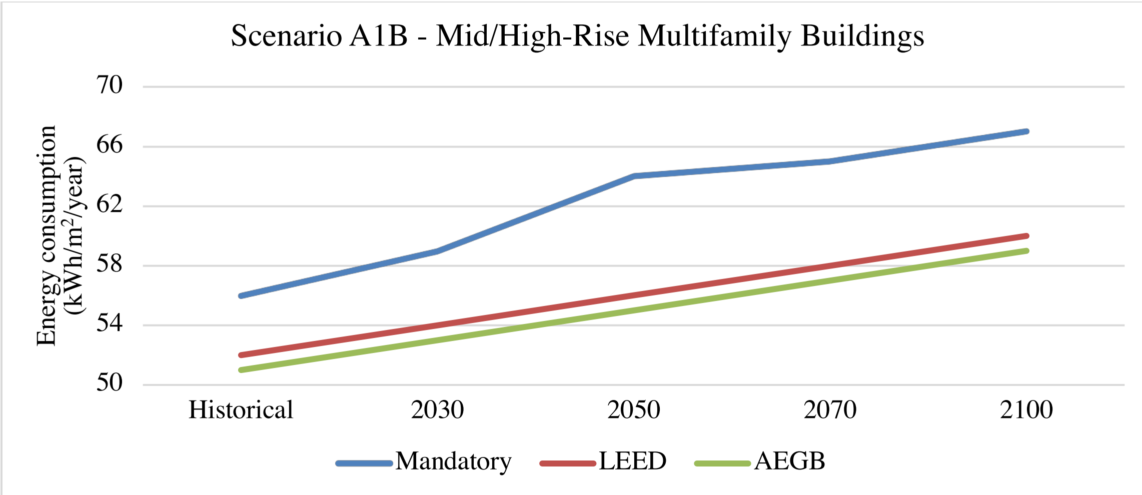


Figure 7.9. Scenario A1B mid/high-rise multifamily energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

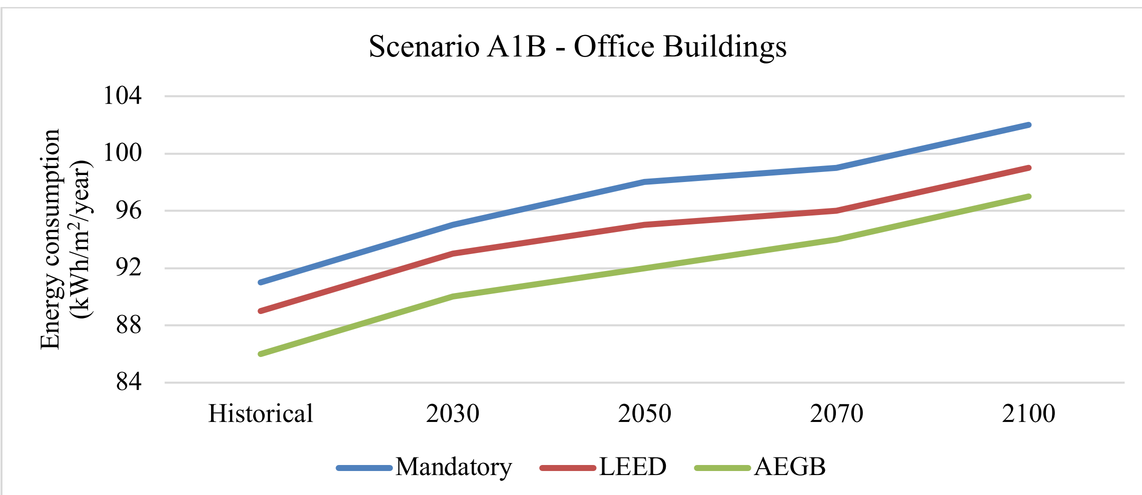


Figure 7.10. Scenario A1B office energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

As expected, energy consumption results obtained from simulations using this scenario are higher than results from the B1 scenario and lower than results from A2. For this scenario, the increase in energy consumption curves is almost linear. The slope is steeper from 2030 to 2050 because for the A1B emission scenario is projected a high-temperature increase between those years.

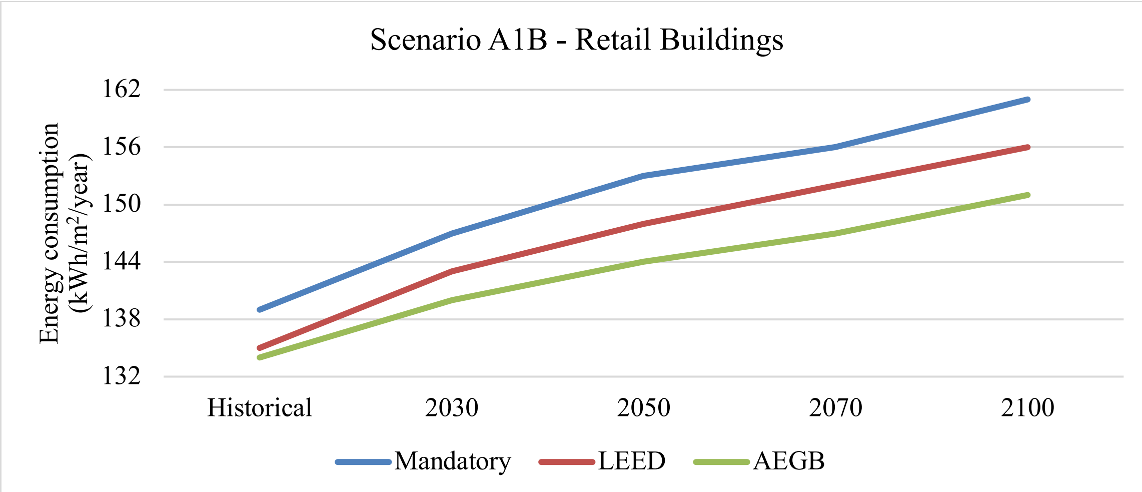


Figure 7.11. Scenario A1B retail energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

7.1.4. A2 Emissions Scenario

The A2 emissions scenario is considered the worst-case scenario for this research. This scenario assumes more regionally oriented economies and high population growth. Results of the simulation process for this emissions scenario presented the higher energy consumption rates (Figures 7.12, 7.13, 7.14, 7.15, and 7.16). Also, the energy curve slope is steeper in comparison to the other two scenarios. From 2070 to 2100 the slope is higher than the rest of the years because temperature increase is higher between those years.

Energy performance of voluntary codes and green building certifications does not present any change just as in the other scenarios. Again, LEED certification performed better for single-family and low-rise multifamily. It is important to mention that despite LEED for Homes requirements is mainly based on the 2012 IECC, the mechanical requirements from the certification credits are stricter than requirements from AEGB and IECC. This can explain that the LEED certification performs the best in this kind of buildings.

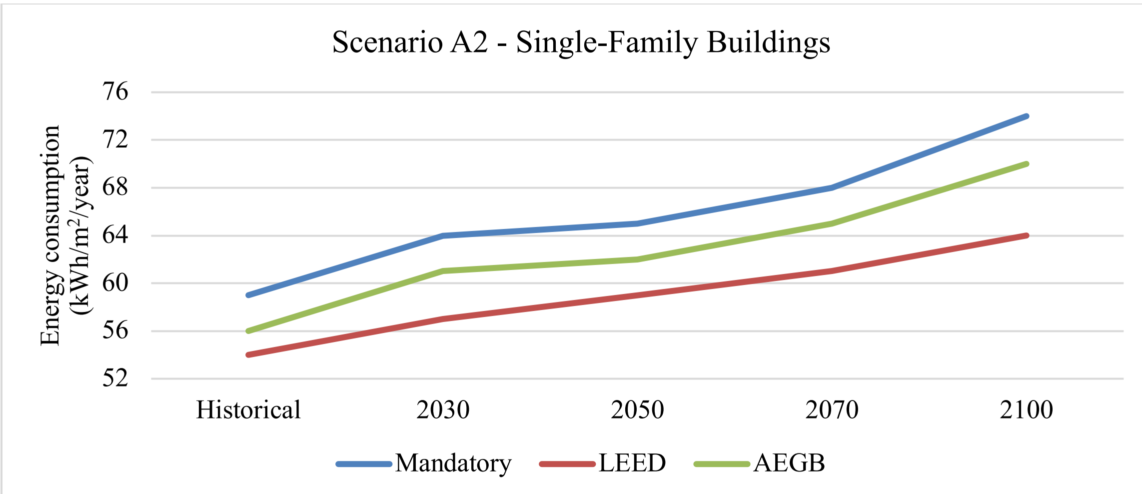


Figure 7.12. Scenario A2 single-family energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

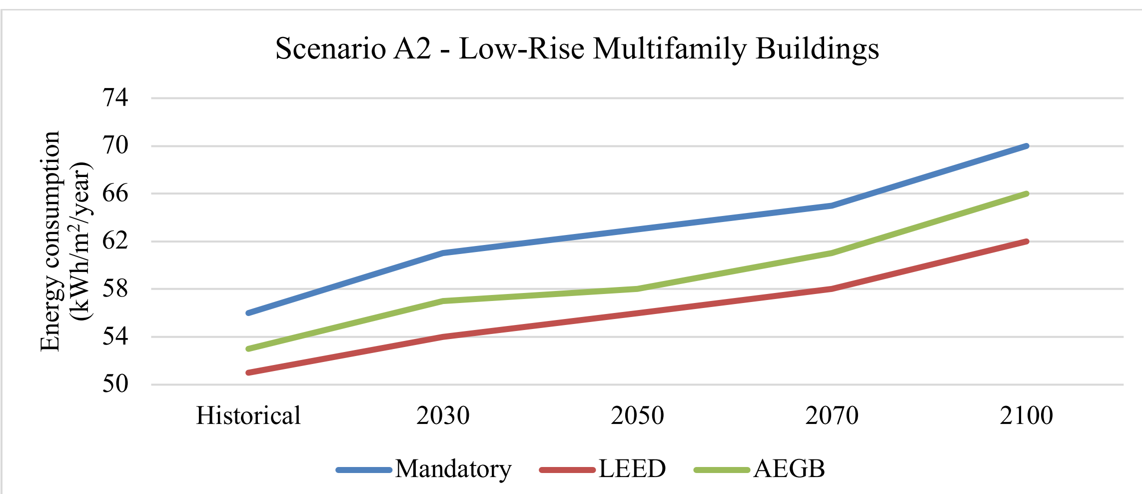


Figure 7.13. Scenario A2 low-rise multifamily energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

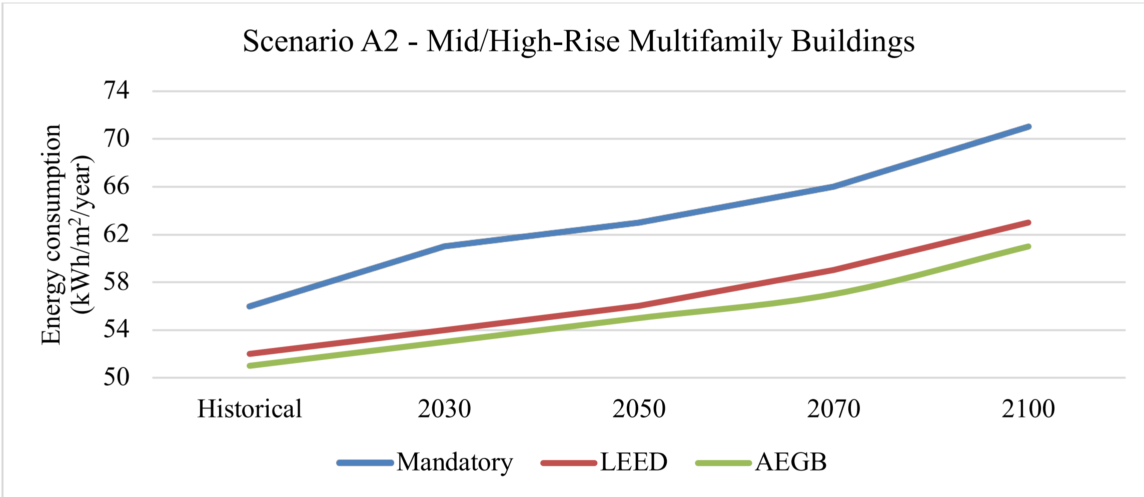


Figure 7.14. Scenario A2 mid/high-rise multifamily energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

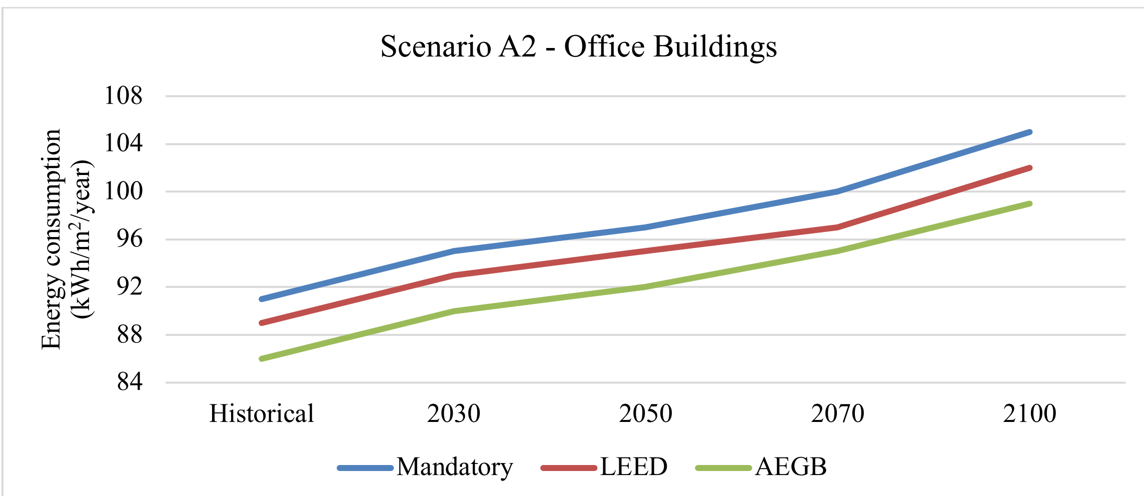


Figure 7.15. Scenario A2 office energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

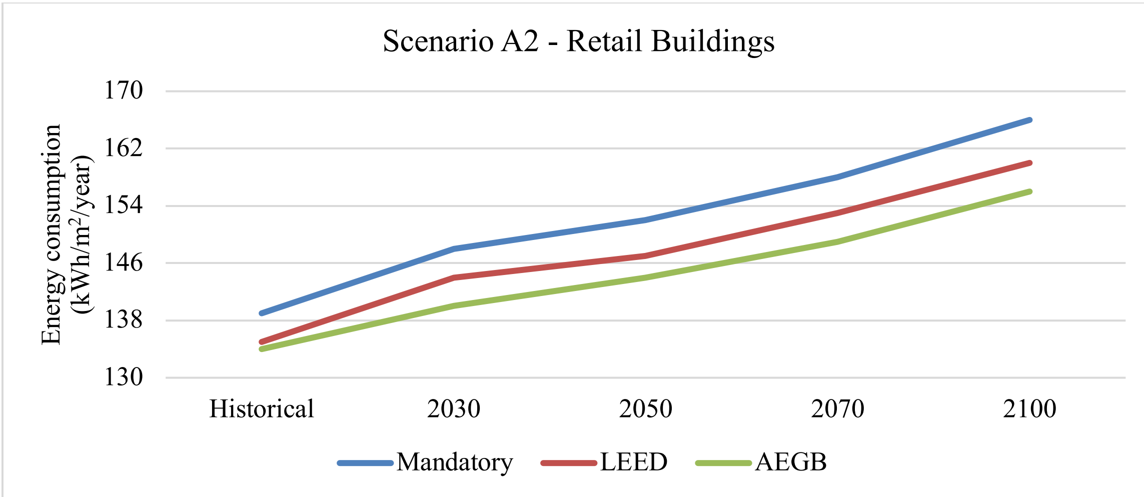


Figure 7.16. Scenario A2 retail energy consumption. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

On the other hand, AEGB requirements are based on the 2015 IECC mandatory code with the City of Austin amendments. The combination of requirements is stricter than ASHRAE Standard 90.1-2010. This explains the slightly higher performance of AEGB over LEED in large buildings. Also, the difference between initial and projected energy consumption for the A2 scenario by the end of the century is higher than any other scenario. The difference of energy performance between the years is discussed in section 7.2.

7.2. Increase of Energy Consumption Comparison

In this section is presented the increase of energy consumption for every building use and mandatory code or voluntary green building certification. Energy consumption increase for years 2050 and 2100 are compared to the initial energy consumption using the historical climate data for Austin. Also, it is discussed which code or certification is the most effective against climate change effects in terms of energy performance.

7.2.1 B1 Emissions Scenario

As presented in section 7.1, the results of simulations performed for the B1 emissions scenario are lower in comparison to results obtained for A1B and A2 scenarios. Figures 7.17 and 7.18 presents the energy consumption increase for the years 2050 and 2100 in comparison to the consumption obtained from historical climate data. Initially, for both years, mandatory codes performed the worst for most of the building uses types.

The most increase in energy consumption in comparison to historical data can be found in 2050 (Figure 7.17). For this year, energy consumption increased between 4 to 6 kWh/m2/year in single-family and low-rise multifamily buildings, between 3 to 4 kWh/m2/year in mid/high-rise multifamily buildings, 8 to 10 kWh/m2/year in retail buildings, and for all codes and certifications consumption increased 5 kWh/m2/year in office buildings. In general, a percental increase in energy consumption is lower in buildings designed under LEED certification requirements, except for retail buildings where AEGB certification energy consumption has a less percental increase.

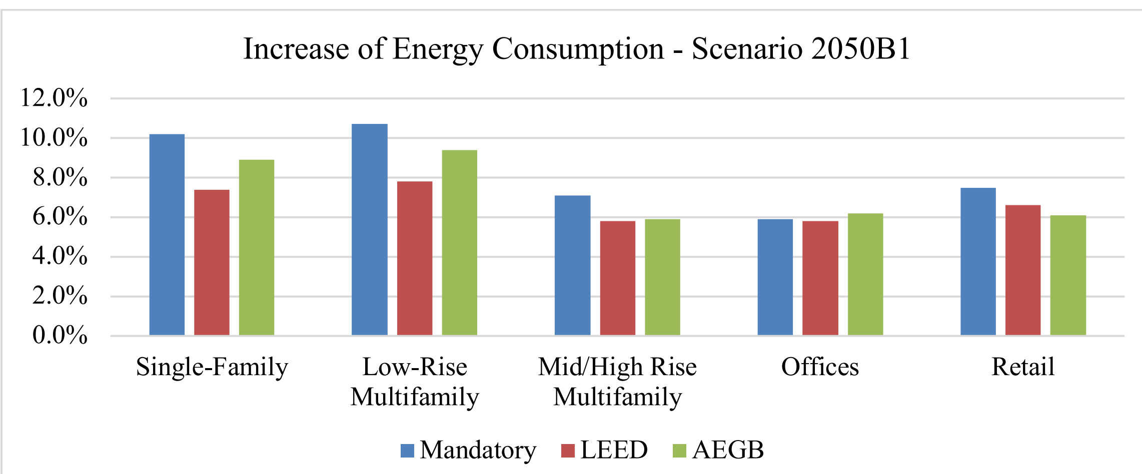


Figure 7.17. Scenario B1 percentage energy consumption increase by 2050 in comparison to historical climate data. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

In the case of 2100, by the end of the century energy consumption is expected to increase between 6 to 7 kWh/m2/year in single-family buildings, between 6 to 8 kWh/m2/year in low-rise multifamily buildings, 5 to 8 kWh/m2/year in mid/high-rise multifamily buildings, 11 to 14 kWh/m2/year in retail buildings, and for all codes and certifications consumption increased 7 kWh/m2/year in office buildings.

By comparing the percental increase for 2100 (Figure 7.18) versus 2050 (Figure 7.17) can be found that energy consumption increased at a lower rate between 2050 and 2100. For example, consumption in single-family buildings using mandatory codes only increased by 1.7% (11.9% in 2100 vs 10.2% in 2050) representing 1 kWh/m2/year. Also, Figure 7.18 presents that small residential buildings designed under LEED certification increased the most energy consumption by 2100. However, in comparison to buildings using AEGB requirements the gross increase in kWh/m2/year is the same and, in the end, they have better performance than buildings designed under mandatory or AEGB requirements.

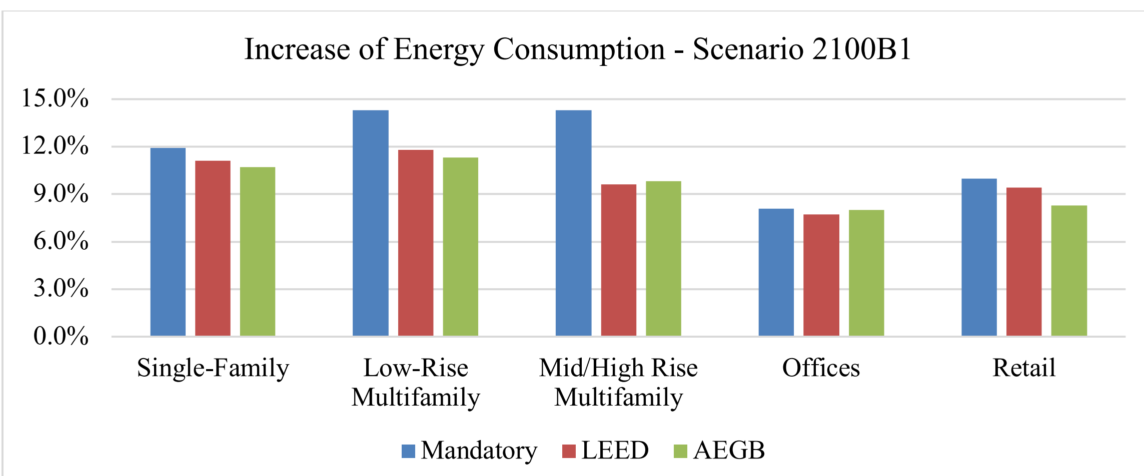


Figure 7.18. Scenario B1 percentage energy consumption increase by 2100 in comparison to historical climate data. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

7.2.2. A1B Emissions Scenario

A1B emissions scenario is considered as a balanced or moderate scenario. For the year 2050, this scenario presented a percental increase in energy consumption higher than B1 and A2 scenarios. As expected, the percentage is higher because in 2050 the A1B emissions scenario has a higher temperature value among the three scenarios. By 2050, energy consumption is expected to increase between 5 to 8 kWh/m2/year in single-family buildings, 5 to 7 kWh/m2/year in low-rise multifamily buildings, between 4 to 8 kWh/m2/year in mid/high-rise multifamily buildings, 11 to 13 kWh/m2/year in retail buildings, and for all codes and certifications consumption increased 7 kWh/m2/year in office buildings. It is important to mention that low-rise multifamily buildings have the same situation as the results for mid/high-rise multifamily in the B1 emissions scenario for the year 2100 (Figure 7.18). In this case, both LEED and AEGB buildings increased 5 kWh/m2/year their energy consumption.

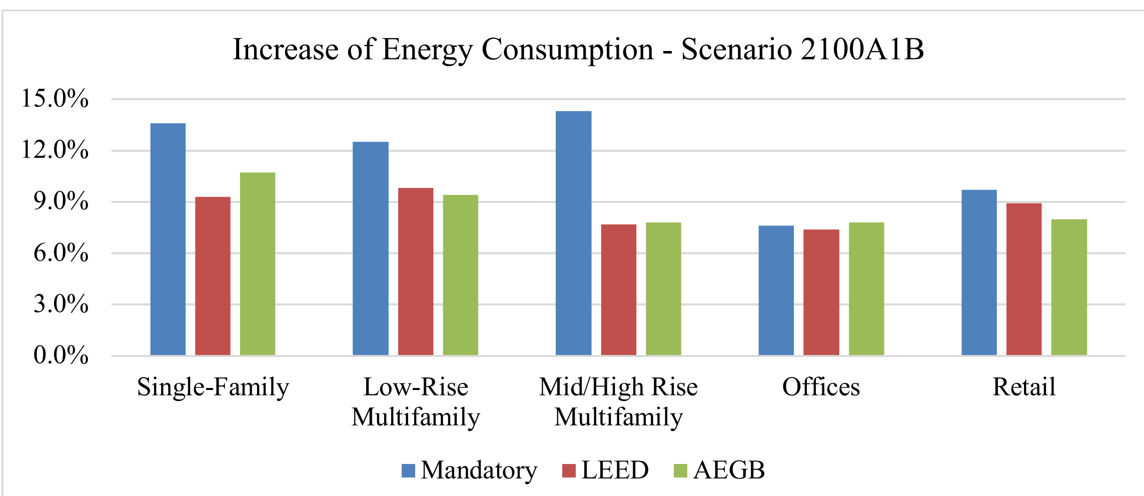


Figure 7.19. Scenario A1B percentage energy consumption increase by 2050 in comparison to historical climate data. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

For the second part, from 2050 to 2100, the energy consumption percental increase is moderate because the temperature increase is lower in comparison to the increase from historical data to 2050. By the end of the century, in comparison to historical data, energy consumption would increase between 9 to 11 kWh/m^2/year in single-family and low-rise multifamily buildings, 8 to 11 kWh/m^2/year in mid/high-rise multifamily buildings, 10 to 11 kWh/m^2/year in office buildings, and 17 to 22 kWh/m^2/year in retail buildings.

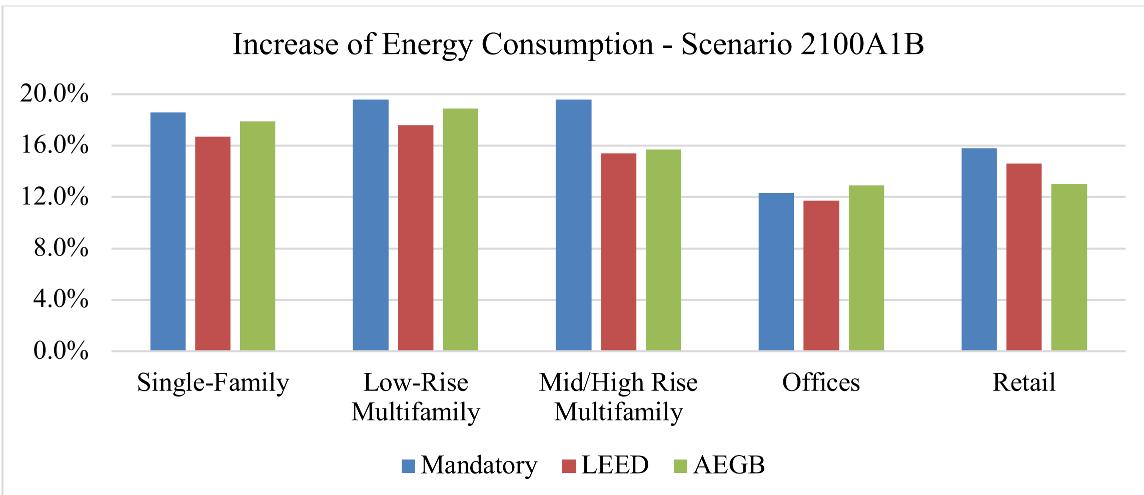


Figure 7.20. Scenario A1B percentage energy consumption increase by 2100 in comparison to historical climate data. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

7.2.3. A2 Emissions Scenario

As expected, for the worst-case emissions scenario the increase in energy consumption is higher in comparison to the other two scenarios. As explained in section 7.2.2, A1B emission scenario has a higher energy consumption percental increase by 2050 in comparison to consumption for historical climate data. However, results obtained for the A2 scenario are slightly lower than the results for the A1B scenario. For this year, energy consumption increased between 5 to 6 kWh/m2/year in single-family buildings, 5 to 7 kWh/m2/year for low-rise multifamily buildings, 4 to 7 kWh/m2/year in mid/high-rise multifamily buildings, 10 to 13 kWh/m2/year in retail buildings, and for both mandatory codes and voluntary certifications consumption increased 6 kWh/m2/year in office buildings.

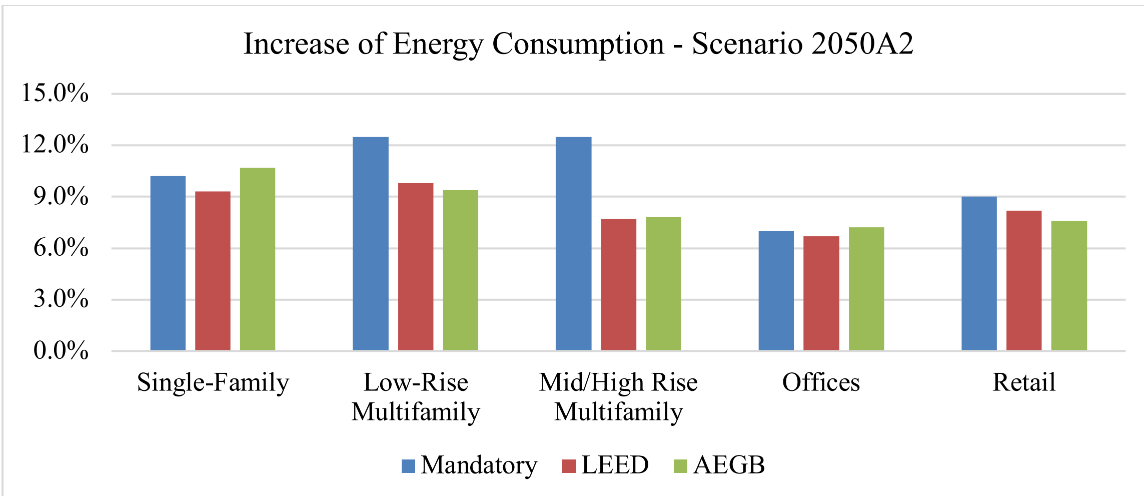


Figure 7.21. Scenario A2 percentage energy consumption increase by 2050 in comparison to historical climate data. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

On the other hand, the most significative energy consumption impacts for this emissions scenario can be found between 2050 to 2100. For this timeframe, the temperature increase rate is higher than for the other two scenarios. By 2100, it is expected an energy consumption increase between 20% to 25% in residential buildings, a percentage higher than any other building use type. On the other hand, retail buildings are adding the most amount of energy used per area, around 22 to 26 kWh/m^2/year.

Increase on energy consumption projections for 2100 are between 10 to 15 kWh/m^2/year in single-family buildings, 11 to 13 kWh/m^2/year in low-rise multifamily buildings, 10 to 15 kWh/m^2/year in mid/high-rise multifamily buildings, 13 to 14 kWh/m^2/year in office buildings, and 22 to 26 kWh/m^2/year in retail buildings.

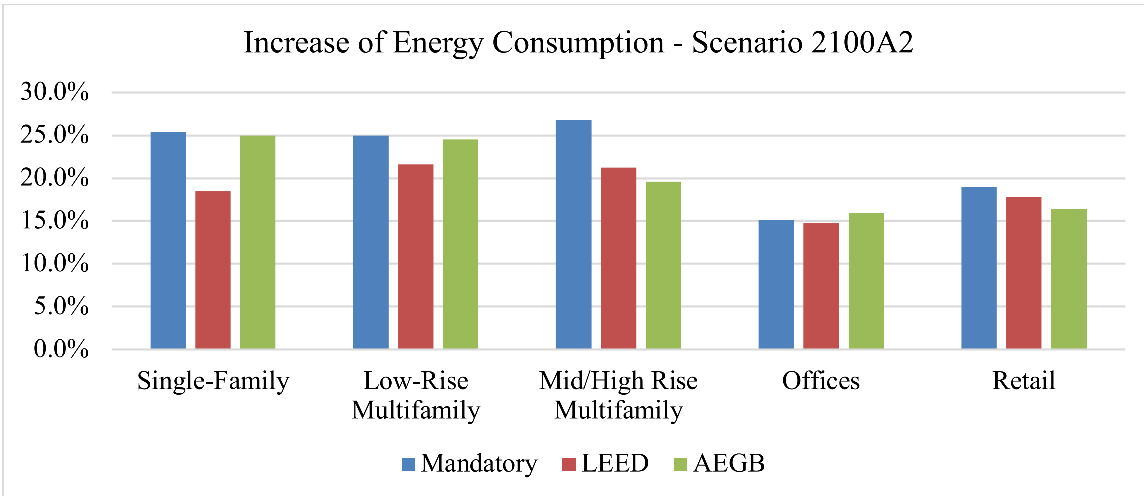


Figure 7.22. Scenario A2 percentage energy consumption increase by 2100 in comparison to historical climate data. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

In all scenarios, the difference of percental increase in energy consumption between mandatory codes and voluntary certifications is significative high for mid/high-rise buildings. A potential reason is the difference of HVAC system efficiency requirements assumptions used for the different building templates. Impact of cooling energy demand is analyzed in section 7.3.

7.3. Analysis of Energy Consumption for Cooling

A climate change study prepared for the City of Austin found that the temperature in the Austin area will dramatically increase by 2100 (Hayhoe, 2014). The study found that there will be fewer cold nights (below 0ºC) more warm nights (over 26.6ºC), hot days (over 37.7ºC) and very hot days (43.3ºC) than in the present. For example, by the end of the century are expected between 35 to 80 hot days per year and between 1 to 20 very hot days per year depending on the climate change scenario used. The increase of hot and very hot days is very significative taking into consideration that the frequency of hot days is 13 per year and very hot days is 2 days every 10 years.

In this section are presented and discussed the increase of cooling demand for the different building uses, climate change scenarios, and construction codes or green building certifications. Figures 7.23, 7.24, 7.25, 7.26, and 7.27 presents by building use type, the results for the energy use for cooling share from the total building energy use. As expected, energy use for cooling increased for the different climate change scenarios due to the increase of outdoor temperature.

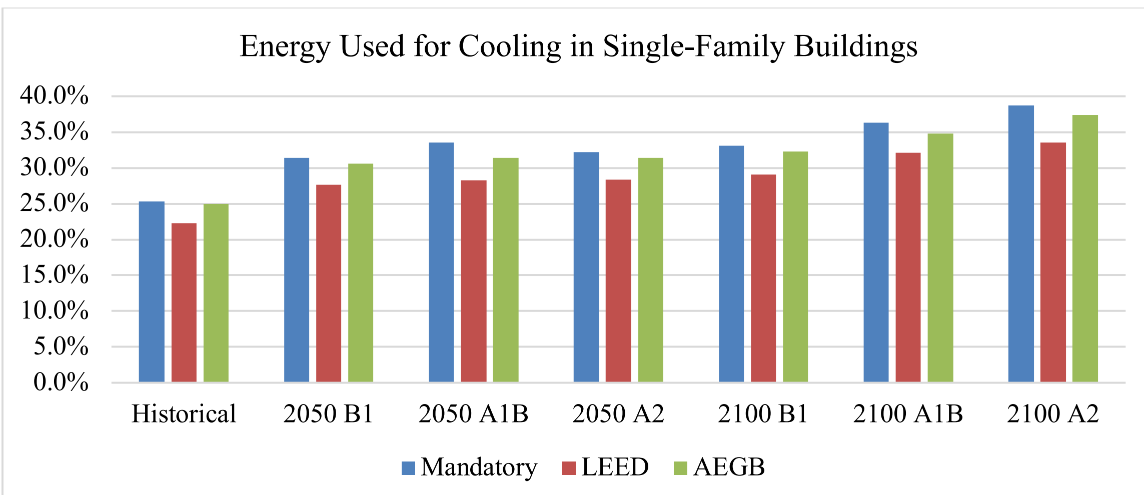


Figure 7.23. Percentage of energy used for cooling in single-family buildings by climate change scenario and design code or certification. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

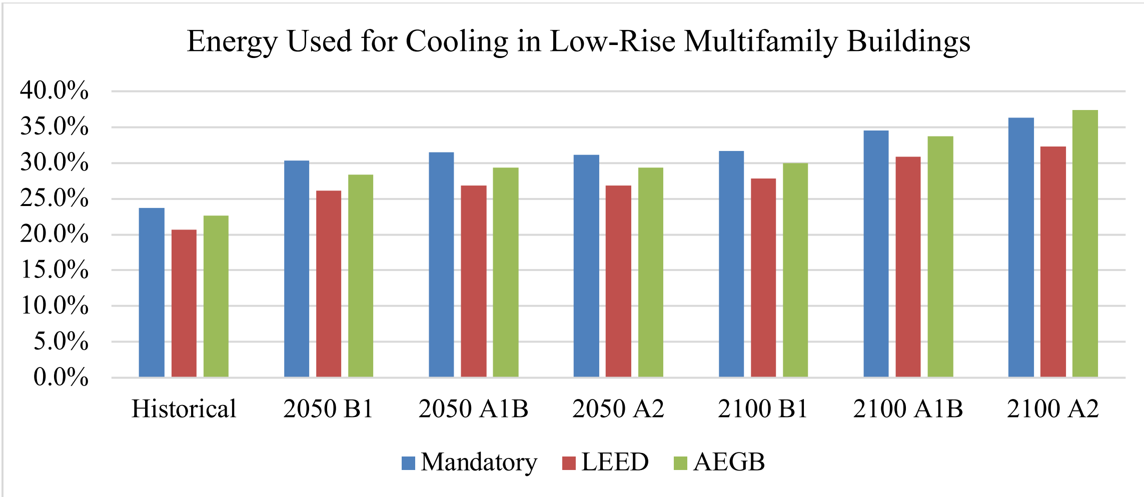


Figure 7.24. Percentage of energy used for cooling in low-rise multifamily buildings by climate change scenario and design code or certification. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

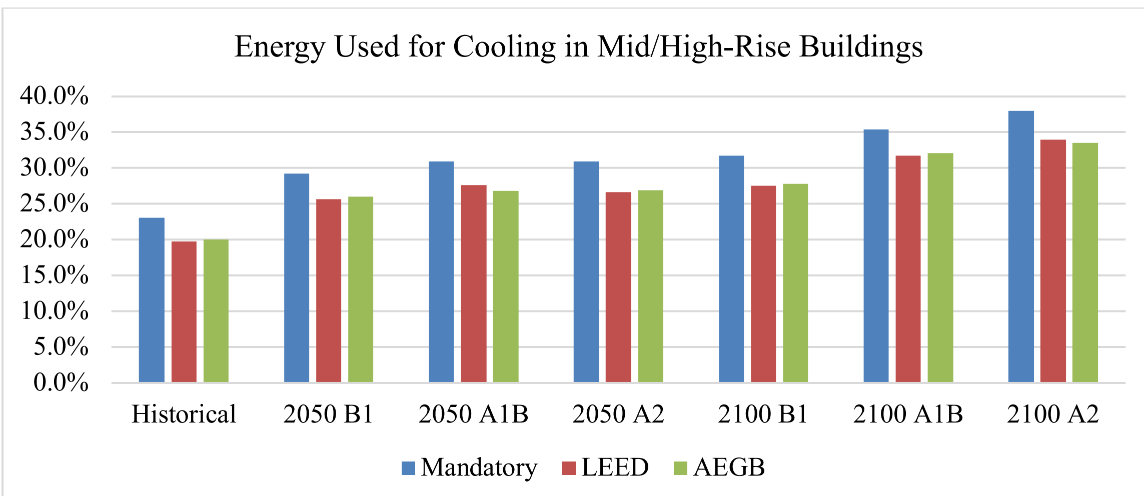


Figure 7.25. Percentage of energy used for cooling in mid/high-rise multifamily buildings by climate change scenario and design code or certification. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

Regarding residential buildings, for single-family buildings, the energy consumption share for cooling is expected to increase between 6.8% to 7.8% for the B1 emissions scenario, 9.7% to 11.1% for the A1B emissions scenario, and 11.2% to 13.5%

for the A2 emissions scenario. In the case of low-rise multifamily buildings, the share is projected to increase between 7.2% to 8.0% for the B1 scenario, 11.9% to 12.3% for the A1B scenario, and 13.5% to 15% for the A2 scenario. Finally, for mid/high-rise buildings the increase will be between 5.8% to 6.5% for the B1 scenario, 8.9% to 9.3% for the A1B scenario, and 13.5% to 15% for the A2 scenario. In general, the residential building uses increased equally their share for cooling. However, single-family buildings were the buildings that resulted in the largest share of energy consumption for cooling.

As presented in Figures 7.23, 7.24 residential buildings designed using the combination of LEED certification measures increased the lower their energy consumption used for cooling. Mostly driven by the energy efficiency requirements proposed for the LEED for Homes certification HVAC credit. On the other hand, mid/high-rise multifamily buildings designed under the AEGB criteria uses slightly less energy for cooling because of the higher HVAC efficiency required by the AEGB multifamily rating system.

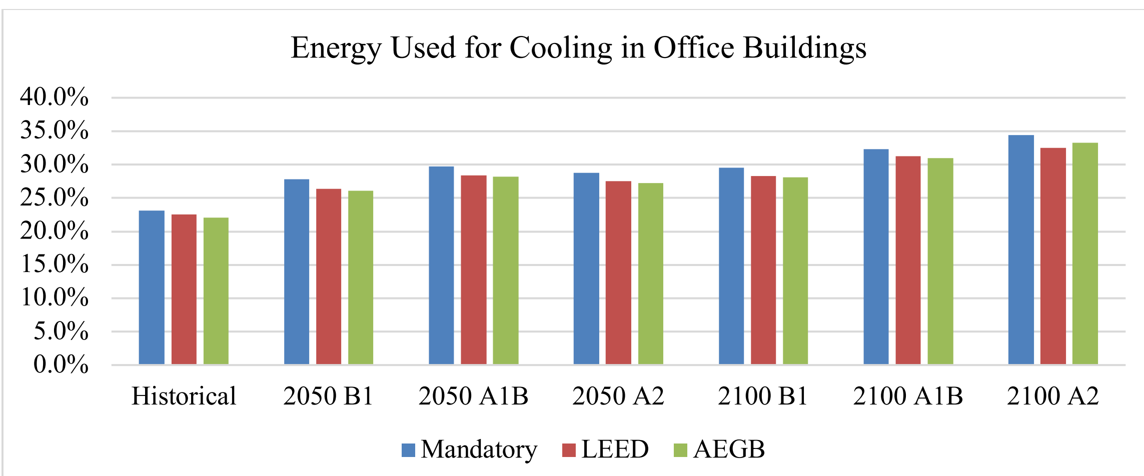


Figure 7.26. Percentage of energy used for cooling in office buildings by climate change scenario and design code or certification. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

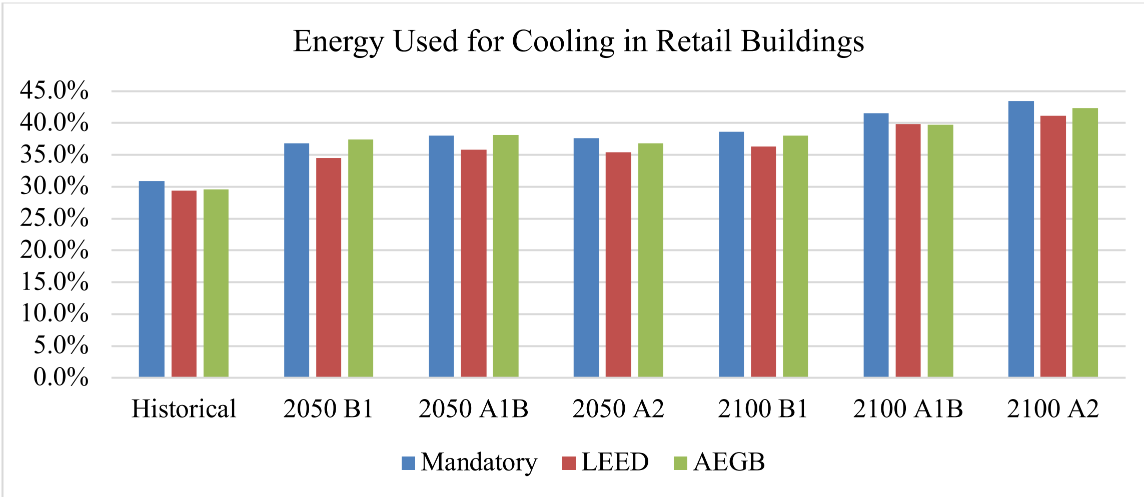


Figure 7.27. Percentage of energy used for cooling in retail buildings by climate change scenario and design code or certification. Source: modeled by Ng Osorio (2019) using Urban Modeling Interface software

In the case of commercial buildings, the share of energy consumption for cooling is greater than for the residential buildings mainly because HVAC energy efficiency requirements are less restrictive in comparison to the requirements for residential buildings. However, the energy consumption increase is lower to the increase in residential buildings. For office buildings, the energy consumption share for cooling is expected to increase between 5.8% to 6.5% for the B1 emissions scenario, 8.9% to 9.3% for the A1B emissions scenario, and 10% to 11.4% for the A2 emissions scenario. In the case of retail use buildings, energy consumption share is projected to increase between 6.9% to 8.3% for the B1 scenario, 10.1% to 10.7% for the A1B scenario, and 11.8% to 12.8% for the B1 scenario.

Chapter 8: Conclusions

After analyzing the results of the several simulations performed for the different mandatory codes and voluntary green building certifications under different climate change scenarios, several conclusions can be made. First, taking into consideration the high population growth that leads urban growth, it is very interesting for planners and policy makers to analyze the building energy performance at the urban scale. By the use of the different urban modeling energy software the new construction can be optimized to increase the building energy performance and retrofits scenarios can be analyzed to find the best practices to reduce energy consumption.

Results from the simulation process shows that it is mostly inevitable to avoid the effects of climate change in the energy performance of buildings. Results presents that regardless the energy design code used for a building, an increase on the energy consumption is unavoidable. However, buildings designed under the different green building certification requirements presented the most resistance against the increase of temperature. For most of the cases, the increase of energy consumption per area was lower for buildings designed under green building certification criteria in comparison to buildings designed under the criteria of the mandatory code. It is important to mention that the building templates used for both buildings designed under LEED and AEGB criteria only included prescriptive measures to accomplish to the minimum requirements of the certification. Therefore, the response against climate change effects can be better if stricter measures are applied to the building.

In the case of Austin, simulation results concluded that cooling represents an important part for the building energy consumption. As expected, buildings including the most efficient HVAC systems have better overall energy performance and response against climate change effects. Besides the recommendation to improve efficiency requirements in mandatory codes, it is clear that the design should be oriented to the inclusion of both active and passive measures to ensure the thermal comfort and reduce the demand for cooling.

Taking into consideration that climate change effects are affecting negatively the building energy performance, another conclusion can be made, more energy consumption results in more energy produced. In order to reach the environmental impact reduction goals, building energy optimization for both new construction or retrofit should be accompanied by the development a more diverse and cleaner energy mix. A cleaner energy production will guarantee greenhouse emissions reduction and a contribution to the climate change mitigation. Finally, it can be translated in a lower temperature increase reducing the energy consumption demand. Also, urban growth should be accompanied by stricter policies focused on reducing the environmental impact. In this case, energy efficiency codes are crucial to sustainable development goals on track.

Appendices

A. Building Templates Baselines

For voluntary green building certification codes values different to presented in the following tables may be used.

A.1. Template for Residential Single-Family and Low-Rise Multifamily Buildings (IP Units)

	Mandatory Requirement	City of Austin Amended	AEGB Certification	Based on	LEED Certification	Based on
Lighting	0.51 W/sq.ft	-	0.51 W/sq.ft	2015 IECC	0.48 W/sq.ft	LEED BD+C: Homes v4 credit
Cooling	14 SEER	-	15 SEER or greater	Single-Family rating system minimum requirement	16.5 SEER or greater	LEED BD+C: Homes v4 credit
Heating	8.2 HSPF	-	Heat Pump 8.2 HSPF or greater	Single-Family rating system minimum requirement	9.0 HSPF or greater	LEED BD+C: Homes v4 credit
Wood Frame Wall	R-19 (R-13 2015 IECC)	Yes	R-19 or greater	2015 IECC	R-13 or greater	Improve 20% 2012 IECC
Fenestration (Fixed)	U-0.35 (U-40 IECC) SGHC-0.25	Yes	U-0.35 SGHC-0.25 or better	2015 IECC	U-0.30 SGHC-0.25 or better	LEED BD+C: Homes v4 credit
Roof	R-38	-	R-38 or greater	2015 IECC	R-38 or greater	Improve 20% 2012 IECC
Floor	R-13	-	R-13 or greater	2015 IECC	R-13 or greater	Improve 20% 2012 IECC
Slab	No Req.	-	No Req.	2015 IECC	No Req.	Improve 20% 2012 IECC
Basement Wall	No Req.	-	No Req.	2015 IECC	No Req.	Improve 20% 2012 IECC
Crawl Space Wall	No Req.	-	No Req.	2015 IECC	No Req.	Improve 20% 2012 IECC
Doors	U-0.61	-	U-0.61 or better	2015 IECC	U-0.61 or better	Improve 20% 2012 IECC

A.2. Template for Mid/High-Rise Residential Multifamily Buildings (IP Units)

	Mandatory Requirement	City of Austin Amended	AEGB Certification	Based on	LEED Certification	Based on
Lighting	0.51 W/sq.ft	-	0.6 W/sq.ft. or lower	Multi-Family rating system minimum requirement	0.6 W/sq.ft or lower	ASHRAE 90.1-2010
Cooling	14 SEER	-	17 SEER or greater	Multi-Family rating system Credit	13 SEER (split system) or greater	ASHRAE 90.1-2010
Heating	8.2 HSPF	-	Heat Pump 8.2 HSPF or greater	Single-Family rating system minimum requirement	7.7 HSPF (split system) or greater	ASHRAE 90.1-2010
Wood Frame Wall	R-19 (R-13 2015 IECC)	Yes	R-15+3 c.i. or greater	Multi-Family rating system minimum requirement	R-13 or greater	ASHRAE 90.1-2010
Fenestration (Fixed)	U-0.35 (U-40 IECC) SGHC-0.25	Yes	U-0.35 SGHC-0.25 or better	Multi-Family rating system minimum requirement	U-0.75 (nonmetal framing) U-0.70 (metal framing) SGHC-0.25 or better	ASHRAE 90.1-2010
Roof	R-38	-	R-25 or greater (insulation entirely above deck)	Multi-Family rating system minimum requirement	R-20 or greater (insulation entirely above deck)	ASHRAE 90.1-2010
Floor	R-13	-	R-30 (joist/framing) or R-8.3 c.i. (mass) or greater	Multi-Family rating system minimum requirement	R-19 (steel-joist) or R-30 (wood framed) or R-8.3 c.i. (mass) or greater	ASHRAE 90.1-2010
Slab	No Req.	-	No Req.	2015 IECC	No Req. or R-7.5 for 12in (heated spaces)	ASHRAE 90.1-2010
Below Grade Wall	No Req.	-	No Req.	2015 IECC	No Req.	ASHRAE 90.1-2010
Crawl Space Wall	No Req.	-	No Req.	2015 IECC	No Req.	ASHRAE 90.1-2010
Doors	R-4.75	-	R-4.75 or better	2015 IECC	U-0.7 or better	ASHRAE 90.1-2010

A.3. Template for Office Buildings (IP Units)

	Mandatory Requirement	AEGB Certification	Based on	LEED Certification	Based on
Lighting	0.82 W/sq.ft.	0.82 W/sq.ft.	2015 IECC – required to improve 15%	0.9 W/sq.ft or lower	ASHRAE 90.1-2010
Cooling	9.5 EER (>240,000 Btu/h systems-air cooled)	9.5 EER (>240,000 Btu/h systems-air cooled)	2015 IECC	9.5 EER (>240,000 Btu/h systems-air cooled)	ASHRAE 90.1-2010
Heating	3.2 COP (>135,000 cooling capacity Btu/h systems-air cooled	3.2 COP (>135,000 cooling capacity Btu/h systems-air cooled	2015 IECC	3.2 COP (>135,000 cooling capacity Btu/h systems-air cooled	ASHRAE 90.1-2010
Wood Frame or Steel Framed Wall	R-19	R-15+3 c.i. or greater	Multi-Family rating system minimum requirement	R-13 or greater	ASHRAE 90.1-2010
Fenestration (Fixed)	U-0.50 SGHC-0.25	U-0.50 SGHC-0.25 or better	2015 IECC	U-0.75 (nonmetal framing) U-0.70 (metal framing) SGHC-0.25 or better	ASHRAE 90.1-2010
Roof	R-25 or greater (insulation entirely above deck)	R-25 or greater (insulation entirely above deck)	2015 IECC	R-20 or greater (insulation entirely above deck)	ASHRAE 90.1-2010
Floor	R-30 (joist/framing) or R-6.3 c.i. (mass) or greater	R-30 (joist/framing) or R-6.3 c.i. (mass) or greater	2015 IECC	R-19 (steel-joist) or R-19 (wood framed) or R-6.3 c.i. (mass) or greater	ASHRAE 90.1-2010
Slab	No Req. or R-7.5 for 12in (heated spaces)	No Req. or R-7.5 for 12in (heated spaces)	2015 IECC	No Req. or R-7.5 for 12in (heated spaces)	ASHRAE 90.1-2010
Below Grade Wall	No Req.	No Req.	2015 IECC	No Req.	ASHRAE 90.1-2010
Crawl Space Wall	No Req.	No Req.	2015 IECC	No Req.	ASHRAE 90.1-2010
Doors	R-4.75	R-4.75	2015 IECC	U-0.7 or better	ASHRAE 90.1-2010

B. Climate files

Source: Meteonorm 7.3 (2019)

Name of site = Austin Airp. TX

Latitude [°] = 30.283, Longitude [°] = -97.700, Altitude [m] = 179

Legend:

- Gh: Mean irradiance of global radiation horizontal
- Bn: Irradiance of beam
- Dh: Mean irradiance of diffuse radiation horizontal
- N: Cloud cover fraction
- Lg: Global luminance
- Ta: Air temperature
- RH: Relative humidity
- Td: Dewpoint temperature
- DD: Wind direction
- FF: Wind speed
- p: Air pressure

Radiation in [W/m²]

Temperature in [°C]

Pressure in [hPa]

Wind speed in [m/s]

Measured parameters (WMO nr: 722540) = Gh, Ta, FF, DD, RR, Td, Sd, Rd

Uncertainty of yearly values: Gh = 3%, Bn = 6 %, Ta = 0.3 °C

Trend of Gh / decade = - %

Variability of Gh / year = 3.9%

P90 and P10 of yearly Gh, referenced to average = 95.1%, 106.1%

B.1. Historical Data
Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: 1991-2005
Temperature: 2000-2009

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	104	101	58	11322	6979	6
Feb	139	134	67	15042	8307	5
Mar	187	158	91	20330	11340	4
Apr	204	134	114	22376	13960	5
May	233	189	105	25716	13563	4
Jun	267	217	114	29738	15171	3
Jul	291	256	112	32422	15625	2
Aug	253	211	105	28199	14350	3
Sep	223	216	83	24707	10931	4
Oct	158	149	73	17428	9164	5
Nov	113	115	57	12398	7074	5
Dec	104	123	50	11352	6274	5
Year	190	167	86	20919	11062	4

Month	Ta	Td	RH	p	DD	FF
Jan	10.3	3.6	63	992	360	3.8
Feb	12.2	5.8	65	992	180	4.0
Mar	16.0	10.0	67	993	180	4.0
Apr	20.2	13.9	67	993	180	4.1
May	24.3	18.3	69	993	180	4.1
Jun	27.4	20.6	66	994	180	3.7
Jul	28.2	21.2	66	994	180	3.2
Aug	28.7	20.8	62	994	180	3.0
Sep	25.5	18.2	64	993	180	2.7
Oct	20.7	14.7	68	993	180	3.1
Nov	15.2	9.1	67	993	180	3.3
Dec	10.2	3.7	64	992	180	3.4
Year	19.9	13.3	66	993	180	3.5

B.2. Year 2030 – Scenario B1

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario B1, year 2030
Temperature: scenario B1, year 2030

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	123	55	12257	6775	5
Feb	146	141	70	15746	8620	5
Mar	193	180	85	20905	10571	4
Apr	209	159	103	22982	12764	5
May	242	181	118	26774	15324	4
Jun	279	243	108	31120	14775	3
Jul	300	280	104	33467	14476	2
Aug	263	228	106	29351	14612	3
Sep	230	229	82	25529	10947	3
Oct	170	163	79	18764	10195	4
Nov	121	119	63	13344	7855	5
Dec	109	143	45	11835	5944	4
Year	198	183	85	21839	11071	4

Month	Ta	Td	RH	p	DD	FF
Jan	10.7	3.6	61	992	360	4.2
Feb	12.9	5.5	60	993	180	4.5
Mar	17.8	9.3	57	993	180	4.9
Apr	22.4	14.4	60	993	180	4.8
May	25.7	18.9	66	993	180	4.6
Jun	28.9	21.7	65	994	180	4.6
Jul	30.7	22.0	60	994	180	4.4
Aug	30.9	21.8	59	994	180	4.1
Sep	28.5	20.3	61	993	180	4.1
Oct	23.2	15.2	61	993	180	4.0
Nov	17.6	10.1	62	993	180	4.1
Dec	12.1	5.3	63	993	180	4.0
Year	21.8	14.0	61	993	180	4.4

B.3. Year 2030 – Scenario A1B

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A1B, year 2030
Temperature: scenario A1B, year 2030

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	122	55	12223	6784	5
Feb	146	142	70	15751	8613	5
Mar	193	157	98	20859	11950	5
Apr	211	153	108	23186	13316	5
May	242	190	113	26808	14540	4
Jun	280	234	116	31232	15580	3
Jul	301	286	102	33556	14485	2
Aug	262	227	104	29221	14391	3
Sep	229	242	73	25554	9945	3
Oct	171	155	81	18879	10652	4
Nov	121	114	66	13330	8197	5
Dec	111	142	48	12124	6020	4
Year	198	180	86	21894	11206	4

Month	Ta	Td	RH	p	DD	FF
Jan	10.7	3.6	61	992	360	4.2
Feb	12.8	5.4	60	993	180	4.5
Mar	18.0	9.4	57	993	180	4.9
Apr	22.6	14.6	60	993	180	4.8
May	25.9	19.1	66	993	180	4.6
Jun	29.1	21.8	65	994	180	4.6
Jul	30.9	22.2	60	994	180	4.4
Aug	31.0	22.0	59	994	180	4.1
Sep	28.6	20.4	61	993	180	4.1
Oct	23.3	15.3	61	993	180	4.0
Nov	17.6	10.2	62	993	180	4.1
Dec	12.2	5.4	63	992	180	4.0
Year	21.9	14.1	61	993	180	4.4

B.4. Year 2030 – Scenario A2

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A2, year 2030
Temperature: scenario A2, year 2030

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	111	119	55	12009	6827	5
Feb	148	138	74	15922	9133	5
Mar	194	167	92	21086	11379	4
Apr	211	154	107	23103	13600	5
May	244	201	109	27060	13846	4
Jun	279	233	114	31075	15514	3
Jul	299	274	107	33423	14796	2
Aug	263	231	103	29293	14079	3
Sep	228	222	86	25396	11559	3
Oct	170	158	79	18764	10405	4
Nov	120	122	62	13198	7851	5
Dec	110	137	48	11941	6055	5
Year	198	180	86	21856	11254	4

Month	Ta	Td	RH	p	DD	FF
Jan	10.7	3.6	61	992	360	4.2
Feb	12.8	5.4	61	993	180	4.5
Mar	17.9	9.4	57	993	180	4.9
Apr	22.5	14.4	60	993	180	4.8
May	26.0	19.2	66	993	180	4.6
Jun	29.1	21.8	65	993	180	4.6
Jul	30.8	22.2	60	994	180	4.4
Aug	31.0	22.0	59	994	180	4.1
Sep	28.5	20.3	61	993	180	4.1
Oct	23.2	15.2	61	993	180	4.0
Nov	17.6	10.2	62	993	180	4.1
Dec	12.3	5.4	63	992	180	4.0
Year	21.9	14.1	61	993	180	4.4

B.5. Year 2050 – Scenario B1

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario B1, year 2050
Temperature: scenario B1, year 2050

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	121	55	12188	6806	5
Feb	148	144	70	15863	8585	5
Mar	194	178	86	21054	10597	4
Apr	210	161	102	23069	12721	5
May	243	206	102	26952	13598	4
Jun	279	237	114	31150	15501	3
Jul	301	278	106	33622	14810	2
Aug	264	236	101	29497	14051	3
Sep	232	230	87	25875	11777	3
Oct	172	175	74	18941	9823	3
Nov	122	136	55	13393	7055	5
Dec	109	117	57	11893	7049	5
Year	199	185	84	21958	11031	4

Month	Ta	Td	RH	p	DD	FF
Jan	10.9	3.8	61	992	360	4.2
Feb	13.2	5.7	60	993	180	4.5
Mar	18.1	9.5	57	993	180	4.9
Apr	22.9	14.8	60	993	180	4.8
May	26.1	19.3	66	993	180	4.6
Jun	29.3	22.0	65	994	180	4.6
Jul	31.2	22.5	60	994	180	4.4
Aug	31.4	22.3	59	994	180	4.1
Sep	29.0	20.8	61	994	180	4.1
Oct	23.8	15.6	60	993	180	4.0
Nov	17.9	10.5	62	993	180	4.1
Dec	12.3	5.5	63	992	180	4.0
Year	22.2	14.4	61	993	180	4.4

B.6. Year 2050 – Scenario A1B

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A1B, year 2050
Temperature: scenario A1B, year 2050

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	112	133	50	12119	6204	5
Feb	147	148	68	15850	8476	4
Mar	193	167	88	20947	10668	5
Apr	212	155	109	23341	13460	5
May	245	197	111	27122	14410	4
Jun	282	224	123	31492	17065	3
Jul	302	291	99	33846	13772	2
Aug	262	233	99	29332	13759	3
Sep	229	220	87	25587	11546	3
Oct	173	185	69	19147	9309	3
Nov	121	123	62	13336	7888	5
Dec	111	135	51	12061	6381	5
Year	199	185	85	22015	11078	4

Month	Ta	Td	RH	p	DD	FF
Jan	11.6	4.5	62	993	360	4.2
Feb	13.5	6.0	60	992	180	4.5
Mar	18.7	10.1	57	993	180	4.9
Apr	23.5	15.4	60	993	180	4.8
May	26.9	20.0	66	994	180	4.6
Jun	30.0	22.7	65	994	180	4.6
Jul	31.8	23.1	60	994	180	4.4
Aug	31.9	22.8	59	994	180	4.1
Sep	29.4	21.2	61	994	180	4.1
Oct	24.3	16.2	60	993	180	4.0
Nov	18.4	11.0	62	993	180	4.1
Dec	12.9	6.1	63	993	180	4.0
Year	22.7	14.9	61	993	180	4.4

B.7. Year 2050 – Scenario A2

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A2, year 2050
Temperature: scenario A2, year 2050

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	121	55	12193	6809	5
Feb	148	146	70	15945	8690	4
Mar	195	175	89	21186	11026	4
Apr	212	173	97	23272	12166	4
May	244	181	120	27094	15792	4
Jun	280	231	119	31306	16335	3
Jul	301	285	101	33643	14291	2
Aug	263	227	106	29500	14711	3
Sep	228	217	86	25409	11436	3
Oct	171	176	72	18946	9505	4
Nov	121	118	64	13317	7960	5
Dec	110	128	53	12007	6641	5
Year	199	182	86	21985	11280	4

Month	Ta	Td	RH	p	DD	FF
Jan	11.3	4.1	61	992	360	4.2
Feb	13.5	6.1	61	993	180	4.5
Mar	18.6	10.0	57	993	180	4.9
Apr	23.5	15.4	61	993	180	4.8
May	26.7	19.9	66	993	180	4.6
Jun	29.8	22.5	65	994	180	4.6
Jul	31.6	23.0	60	994	180	4.4
Aug	31.8	22.7	59	994	180	4.1
Sep	29.4	21.2	62	994	180	4.1
Oct	24.0	15.9	61	993	180	4.0
Nov	18.3	10.9	62	993	180	4.1
Dec	13.1	6.2	63	993	180	4.0
Year	22.6	14.8	61	993	180	4.4

B.8. Year 2070 – Scenario B1

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario B1, year 2070
Temperature: scenario B1, year 2070

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	122	55	12266	6796	5
Feb	148	144	70	15876	8611	5
Mar	195	178	86	21088	10613	4
Apr	211	164	101	23241	12693	5
May	244	206	102	26972	13621	4
Jun	280	239	113	31270	15389	3
Jul	301	279	106	33675	14882	2
Aug	264	237	101	29524	14051	3
Sep	232	230	87	25902	11718	3
Oct	172	176	74	18972	9755	3
Nov	122	140	54	13418	6977	4
Dec	111	146	46	12035	5853	4
Year	199	189	83	22020	10913	4

Month	Ta	Td	RH	p	DD	FF
Jan	11.3	4.1	61	992	360	4.2
Feb	13.6	6.1	60	993	180	4.5
Mar	18.5	9.9	57	993	180	4.9
Apr	23.3	15.2	60	993	180	4.8
May	26.5	19.7	66	993	180	4.6
Jun	29.6	22.3	65	994	180	4.6
Jul	31.5	22.9	60	994	180	4.4
Aug	31.7	22.6	59	994	180	4.1
Sep	29.4	21.2	61	994	180	4.1
Oct	24.2	16.0	60	993	180	4.0
Nov	18.3	10.8	62	993	180	4.1
Dec	12.8	5.9	63	993	180	4.0
Year	22.5	14.7	61	993	180	4.4

B.9. Year 2070 – Scenario A1B

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A1B, year 2070
Temperature: scenario A1B, year 2070

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	135	49	12170	6178	5
Feb	147	149	67	15845	8321	4
Mar	193	175	86	20947	10612	4
Apr	211	157	104	23137	12987	5
May	246	174	127	27361	16501	5
Jun	282	254	103	31684	14477	2
Jul	303	289	98	33924	14143	2
Aug	263	229	104	29461	14279	3
Sep	230	224	84	25759	11481	3
Oct	173	173	76	19218	10018	4
Nov	122	131	57	13397	7146	5
Dec	110	143	47	11993	6037	4
Year	199	186	84	22075	11015	4

Month	Ta	Td	RH	p	DD	FF
Jan	12.2	5.1	62	993	360	4.2
Feb	14.3	6.7	60	993	180	4.5
Mar	19.4	10.7	57	993	180	4.9
Apr	24.2	16.1	61	993	180	4.8
May	27.6	20.7	66	993	180	4.6
Jun	30.7	23.4	65	994	180	4.6
Jul	32.5	23.8	60	994	180	4.4
Aug	32.6	23.4	59	994	180	4.1
Sep	30.2	21.9	61	993	180	4.1
Oct	25.2	17.1	61	993	180	4.0
Nov	19.2	11.6	62	993	180	4.1
Dec	13.7	6.7	63	993	180	4.0
Year	23.5	15.6	61	993	180	4.4

B.10. Year 2070 – Scenario A2

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A2, year 2070
Temperature: scenario A2, year 2070

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	122	55	12250	6815	5
Feb	150	149	69	16123	8650	4
Mar	197	175	89	21312	11045	4
Apr	214	151	112	23512	14289	5
May	246	190	118	27353	15638	4
Jun	282	240	113	31533	15682	3
Jul	300	279	106	33675	15328	2
Aug	263	228	106	29510	14861	3
Sep	229	217	87	25607	11529	4
Oct	172	175	75	18979	9825	4
Nov	122	118	64	13368	8187	5
Dec	111	133	52	12069	6499	4
Year	200	182	87	22108	11529	4

Month	Ta	Td	RH	p	DD	FF
Jan	12.2	5.1	62	992	360	4.2
Feb	14.5	6.9	60	993	180	4.5
Mar	19.6	10.9	57	993	180	4.9
Apr	24.6	16.4	60	993	180	4.8
May	27.9	21.0	66	993	180	4.6
Jun	30.9	23.6	65	994	180	4.6
Jul	32.6	24.0	61	994	180	4.4
Aug	32.8	23.6	59	994	180	4.1
Sep	30.5	22.3	61	994	180	4.1
Oct	25.2	17.0	60	993	180	4.0
Nov	19.3	11.8	62	993	180	4.1
Dec	13.9	7.0	63	993	180	4.0
Year	23.7	15.8	61	993	180	4.4

B.11. Year 2100 – Scenario B1

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario B1, year 2100
Temperature: scenario B1, year 2100

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	114	124	55	12347	6766	5
Feb	147	144	70	15847	8592	5
Mar	195	179	85	21112	10565	4
Apr	214	169	100	23488	12557	5
May	244	207	102	27013	13622	4
Jun	281	245	108	31483	14326	3
Jul	301	281	105	33705	14897	2
Aug	264	232	102	29564	14009	3
Sep	231	238	77	25755	10432	3
Oct	172	165	76	19020	10012	4
Nov	123	118	66	13491	8284	5
Dec	113	134	53	12227	6646	4
Year	200	187	83	22088	10892	4

Month	Ta	Td	RH	p	DD	FF
Jan	11.6	4.5	61	992	360	4.2
Feb	14.0	6.5	60	993	180	4.5
Mar	18.9	10.2	57	993	180	4.9
Apr	23.7	15.6	60	993	180	4.8
May	26.9	20.1	66	994	180	4.6
Jun	30.0	22.7	65	994	180	4.6
Jul	31.8	23.1	60	994	180	4.4
Aug	32.0	23.0	59	994	180	4.1
Sep	29.7	21.5	61	994	180	4.1
Oct	24.5	16.4	61	993	180	4.0
Nov	18.7	11.2	62	993	180	4.1
Dec	13.3	6.4	63	993	180	4.0
Year	22.9	15.1	61	993	180	4.4

B.12. Year 2011 – Scenario A1B

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A1B, year 2100
Temperature: scenario A1B, year 2100

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	114	123	55	12299	6791	5
Feb	146	141	70	15759	8691	5
Mar	193	158	98	20964	12047	5
Apr	209	162	99	23043	12442	5
May	247	200	109	27503	14201	4
Jun	282	231	119	31648	16531	3
Jul	302	283	103	33938	14838	2
Aug	263	232	103	29592	14569	3
Sep	231	230	83	25943	11356	3
Oct	173	179	73	19118	9741	3
Nov	122	139	54	13453	6985	5
Dec	110	124	55	11927	6968	5
Year	199	184	85	22099	11263	4

Month	Ta	Td	RH	p	DD	FF
Jan	12.8	5.7	62	992	360	4.2
Feb	15.0	7.5	60	993	180	4.5
Mar	20.1	11.4	57	993	180	4.9
Apr	25.0	16.8	60	993	180	4.8
May	28.3	21.4	66	994	180	4.6
Jun	31.5	24.1	65	994	180	4.6
Jul	33.2	24.5	60	994	180	4.4
Aug	33.2	24.1	59	994	180	4.1
Sep	31.0	22.7	62	994	180	4.1
Oct	26.1	17.9	61	994	180	4.0
Nov	20.0	12.4	62	993	180	4.1
Dec	14.4	7.5	63	993	180	4.0
Year	24.2	16.3	61	993	180	4.4

B.13. Year 2100 – Scenario A2

Radiation model = Default (hour); Temperature model = Default (hour)
Diffuse radiation model = Default (hour) (Perez)
Radiation: scenario A2, year 2100
Temperature: scenario A2, year 2100

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N
Jan	113	122	55	12262	6814	5
Feb	152	159	66	16408	8293	4
Mar	198	190	83	21414	10450	4
Apr	216	158	109	23740	13972	5
May	249	197	115	27771	15609	4
Jun	283	229	122	31815	17276	3
Jul	298	284	100	33599	14406	2
Aug	262	235	98	29567	13972	3
Sep	230	217	91	25762	12764	3
Oct	172	171	74	19090	9629	4
Nov	123	137	56	13505	7085	5
Dec	112	148	45	12139	5850	4
Year	201	187	85	22256	11343	4

Month	Ta	Td	RH	p	DD	FF
Jan	13.3	6.2	62	993	360	4.2
Feb	15.6	8.1	61	993	180	4.5
Mar	20.8	12.1	57	993	180	4.9
Apr	25.9	17.7	60	993	180	4.8
May	29.3	22.4	66	994	180	4.6
Jun	32.3	24.9	65	994	180	4.6
Jul	33.8	25.0	60	994	180	4.4
Aug	33.9	24.7	59	994	180	4.1
Sep	31.8	23.5	61	994	180	4.1
Oct	26.7	18.5	61	993	180	4.0
Nov	20.5	12.9	62	993	180	4.1
Dec	14.8	7.8	63	993	180	4.0
Year	24.9	17.0	61	993	180	4.4

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